PHYSICAL ASSESSMENT TO IMPROVE THE IDENTIFICATION OF MODIFIABLE PHYSIOLOGICAL FALL RISK FACTORS IN HEALTHY COMMUNITY-DWELLING OLDER ADULTS

By

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DECLARATION

I am aware of The University of Warwick regulations governing plagiarism and I declare that this document is all my work except where I have stated otherwise.

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ABSTRACT

As the population aged >60 years grows, the number of people falling and subsequent injury increases. Falls have a devastating effect on older adults living in the community in terms of morbidity, mortality, and loss of independence. In general, a positive answer to falls screening questions, or opportunistic identification of fall risk through primary care pathways, establishes an older adult as being at risk of a fall and warrants further investigation using multifactorial fall risk assessments (MFRA). At the MFRA stage, standardised fall risk assessment tools are directed at identifying the presence of physiological impairments and risk of falling in older adults. Although these tools identify which intervention domain a person needs, information from these assessments does not inform the health professional of the underlying causes of poor physical function and performance. Therefore, the purpose of this project was to develop an assessment tool that may potentially identify modifiable fall risk factors in this population.

A conceptual framework for objectively measuring modifiable physical impairments and a novel assessment procedure (**P**erformance **D**eficit **T**est for **Com**munity-dwelling older adults (PDT-Com)) were introduced (Chapter 2). This was followed by a brief description of the scoring criteria of the PDT-Com assessment and discussion of the validity of its contents (Chapters 3 and 4). Chapter 5 reviewed current literature on falls prevention guidelines and assessment procedures which identified a need to better detect modifiable risk factors. The first study was a systematic review examining the objective measurement of lower-extremity muscle strength in community-dwelling older adults (Chapter 6). The second study was another systematic review (Chapter 7) examining current assessment tools which are used to identify modifiable functional status and fall risk factors in this population. The results further supported the need for a newly designed assessment tool that can objectively measure modifiable physical impairments to better inform the contents of an exercise intervention.

The first experimental study (Chapter 7) was carried out to determine reference values of strength for ten lower-extremity muscle actions using hand-held dynamometry in a small cohort of community-dwelling older adults. These data were used to develop an objective scoring system. A second experimental study (Chapter 8) investigated intra- and inter-rater reliability of the PDT-Com in community-dwelling older adults. Assessment of movement competency is reliable and can confidently be applied by suitably trained individuals when a standardised procedure is used.

A final experimental study examined the effect and feasibility of a three-month home and group exercise intervention directed by initial assessment using the PDT-Com. For the experimental group, a corrective exercise programme was prescribed based on each person's PDT-Com score. The mean total PDT-Com scores for the exercise group were significantly improved compared to baseline scores. Conversely, mean PDT-Com scores in the control group marginally decreased over time from baseline scores. Between groups differences in mean PDT-Com scores were observed between groups suggesting that those subjects receiving an individualised exercise programme improved their physical function compared to the control group. This new assessment tool is a promising but untested approach to reducing falls and falls-related injury through the identification, and possible causes, of modifiable fall risk factors at the MFRA stage. A physiological assessment paradigm serves to promote a primary preventative approach to the management of falls in active community-dwelling older adults.

ABBREVIATIONS

Abbreviation	Definition
30sCRT	30-second Chair Rise Test
AAA	Athletic Ability Assessment
ADL	Activity of Daily Living
BBS	Berg Balance Scale
CG	Control Group
FL	Forward Lunge
FMS	Functional Movement Screen
HHD	Hand-held Dynamometer
HMS	Human Movement System
ICC	Intra-class Correlation Coefficient
IG	Intervention Group
LPHC	Lumbopelvic Hip Complex
MCS	Movement Competency Screen
MFRA	Multifactorial Falls Risk Assessment
MMT	Manual Muscle Testing
MSK	Musculoskeletal
NASM	National Academy of Sports Medicine
OEP	Otago Exercise Programme
PDT-Com	Performance Deficit test for Community-dwelling Older Adults
POMA	Performance Oriented Mobility Assessment
PPA	Physiological Profile Assessment
RCT	Randomised controlled trial
ROM	Range of Motion
S&C	Strength & Conditioning
SLSQ	Single-Leg Squat
SQ	Squat
TUG	Timed Up and Go Test

1 INTRODUCTION

This chapter discusses the rationale for a change of approach to physical assessments in falls research, describes operational definitions relevant to this thesis, outlines the aims and objectives followed by an outline of the organisational structure.

1.1 THESIS RATIONALE

Falls and consequent injuries are a major public health problem and account for 40% of all injury-relatedd eaths worldwide in the older adult population (1, 2). Healthcare costs of falls in older adults are increasing all over the world (2). In the United Kingdom (UK), it is estimated that 30% of community-dwelling adult over the age of 65 years, and 50% over 80 years, fall at least once each year (3). A review of the literature shows objective, reliable and valid fall risk assessment protocols can assist in identifying individuals at risk to make recommendations and optimise prevention strategies (4). It has been widely acknowledged that in order to reduce the burden of falls in older adults, easy-to-administer fall prevention programmes need to be developed and implemented nationwide (2, 3). Modifiable physiological risk factors for falling in older adults are also well documented in the literature (5-53). Examining the falls prevention literature clearly demonstrates that exercise interventions, whether used as a stand-alone strategy or as part of a multifactorial approach, can effectively lower fall risk/incidence rates by targeting modifiable physiological fall risk factors (5, 15, 22, 48, 54-63). Yet, there does not appear to be any valid and reliable assessment tool designed to determine and standardise how an individual's physical function and movement competency is measured for guiding exercise prescription. Several studies conclude that more research is needed to determine more effective exercise interventions aimed specifically at fall prevention (63-65). Furthermore, it has been proposed that targeted single-intervention programmes may be more acceptable and cost-effective (66). Gates *et al*. (31) further suggest that multifactorial interventions that 'provide treatments to address risk factors rather than information and referral may be more effective.'

Despite the plethora of controlled trials in fall prevention research measuring the effectiveness of exercise interventions, the current evidence indicates that there is no intervention that can be recommended over another (26). This is, in part, supported by the few studies to have directly compared exercise interventions, and will be made clear in the following chapters. One study compared a ten-week balance and stepping programme with Tai Chi. The authors found the former to be more effective, but the exercises used in the intervention were directly related to the outcome measures (67). As a result, the Tai Chi intervention with its emphasis on slow and controlled movements, was never likely to improve the trial outcome measures of dynamic balance responses and stepping speed. Another which compared the Otago Exercise Programme, which is a strength and balance exercise programme, with Tai Chi on several physiological outcomes found mixed results, and the authors were unable to determine which was the most effective intervention to prevent falls (63). A third study (68) determined the long-term effects of three strength and balance exercise interventions on physical performance, fall-related psychological outcomes, and falls in older adult. It was concluded that the findings did not translate to improved fall-related psychological outcomes or reduce the incidence of falls.

The first step in preventing falls is to identify an older adult's level of fall risk to determine which intervention strategy is most suitable. Based on the evidence, it may be more beneficial to determine the contents of an exercise intervention based on individual deficits, imbalances and dysfunctions. This approach requires an analysis of both the activity to be improved, restored, or preserved and of the exercises that may be used in these endeavors. However, for an intervention to be effective, a fundamental analysis of individual requirements is firstly needed. That is, to identify individual modifiable deficits in lower-extremity muscle strength, together with a comprehensive analysis to identify dysfunctions in gait, balance and movement ability that will facilitate the prescription of corrective exercises.

1.2 OPERATIONAL DEFINITIONS

1.2.1 What Constitutes a Fall?

The definition of what constitutes a fall, and the method of identifying when a fall has occurred can vary between scientific research studies (69), and one must consider this disparity carefully before interpreting any research findings. One early definition, but one which lacks practicality for use in scientific study, was by Isaacs (70) in which a fall was described as 'when the vertical line which passes through the centre of mass of the human body comes to lie beyond the support base and correction does not take place in time'. In 1988 Tinetti (71) defined a fall as 'an event which results in a person coming to rest unintentionally on the ground or other lower level, not as a result of a major intrinsic event (such as stroke) or overwhelming hazard'.

The definition which is consistent with The International Classification of Diseases (72) states that a fall is 'inadvertently coming to rest on the ground, floor or other lower level, excluding intentional change in position to rest on furniture, wall or other objects'. A recent National Institute for Health and Clinical Excellence (NICE) guidance paper (3) has used the combined American Geriatric Society and British Geriatric Society definition which states that a fall is 'an event whereby an individual comes to rest on the ground or another lower level with or without the loss of consciousness'. This apparent diversity of definitions means that it can be difficult to compare results across studies. However, a Prevention of Falls Network Europe (ProFaNE) consensus statement recommends a fall to be defined as 'an unexpected event in which the participants come to rest on the ground, floor, or lower level'. Including the lay perspective '...have you had any fall including a slip or trip in which you lost your balance and landed on the floor or ground or lower level?' (10).

1.2.2 Classification of a Fall

Falls can be classified in several ways. They can be explained, such as a stumble or syncope (loss of consciousness), or occur where no apparent causal factor can be identified (73). Falling can also be classified as either intrinsic or extrinsic; the former where some event or medical condition affects balance, posture and/or gait ability; the latter where an environmental factor is the main contributor. Additionally, research often dichotomises between injurious and non-injurious falls due to risk factors for these types of falls being different (74). However, this method classifies falls by their outcome, which is unknown at the point that a fall occurs.

Currently fallers are classified as non-fallers or recurrent fallers, with classifications differing between studies. A faller is generally defined as someone who has had at least one fall in a particular time period, usually six months or one year (75). A recurrent faller is usually defined as someone who has fallen twice or more in a similar six months to one year period (73). However, research (13) has demonstrated that persons falling only once have similar results in postural sway, visual contrast sensitivity, reaction time and quadriceps strength testing compared to non-fallers. Therefore, some researchers classify a faller as someone who has had two or more falls, and a recurrent faller as someone who has had more than three falls in a defined time period (4, 10).

1.2.3 High-Functioning Community-dwelling Older Adults

Age-related changes in musculoskeletal performance serve as independent predictors and strong determinants of the rate at which an older adult may progress towards mobility disability (22-25). Left untreated, impairments can progress to a stage of functional limitation, manifesting as difficulty with or inability to perform a host of fundamental physical tasks of daily living such as rising from a chair and stair climbing (10, 11). Thus, the early identification of these impairments may provide healthcare professionals the opportunity to identify at-risk individuals much sooner, allowing early use of preventative and countermeasure strategies. As a result, high-functioning community-dwelling older adults are the main focus of this thesis.

The criteria for determining who is deemed 'high-functioning' in community-dwelling older adults vary between studies. For example, in a study by Seeman *et al* (76) participants were screened on the basis of six criteria to identify a relatively high functioning cohort, which is reported to represent the top third of their age group (70-79 years) in terms of physical and cognitive function. Currently no standard criteria exist, rather, the study methodology sets out how a particular 'high-functioning' cohort will be selected and in some cases, these can simply be stated as 'non-fallers'.

1.2.4 Strength & Conditioning

Strength & conditioning (S&C) is a branch of sports medicine science which deals primarily with increasing human physical performance and preventing injuries in predominantly athletic populations. The safe and evidence-based application of known principles of physics, physiology and psychology enable an individual to reach a higher level of physical function (77). Exercise prescription in the sports medicine paradigm is based on a 'needs analysis' or 'appraisal', and is a crucial aspect of safe, individualised corrective exercise and athletic performance programming

(77). Research in the exercise sciences reveals that optimal assessments and exercise programmes are those that are individualised, and the effects of exercise are specific to the systems that are targeted to adapt. Although the basic principles of exercise prescription are generic, these principles can be modified depending on the limitations or restrictions based on the health of the individual (78-81).

Practitioners with an educational background in S&C have specialist skills and competencies for conducting an assessment, and in the planning and implementation of exercise intervention programmes for human physical performance. This includes processes that result in physical adaptation through integrating fitness components into a structured programme, which allows for recovery, monitoring and complements other aspects of development. The S&C practitioner typically works together in a professional setting, alongside sports medicine physicians, orthopaedic consultants, corrective exercise specialists, physiotherapists, sports therapists and other health professionals.

Specificity of exercise, training and monitoring is among the most important considerations for an S&C practitioner when designing assessment tools and subsequent exercise programmes. This is especially the case when performance enhancement of a physical task is the primary goal or outcome measure. The term specificity does not mean that two variables are identical; rather specificity deals with the degree of association between exercise variables (77). This exercise association, if large, will elicit a large degree of 'transfer of training effect' leading to greater physical adaptations. The kinematic (movement) and kinetic (force) associations between training programmes or training exercises and physical performance need to consider the movement patterns involved for optimum transfer of motion and force (77, 82, 83). These transfer characteristics include the following:

- movement patterns (complexity, position, range, contraction type, execution)
- force magnitude (average and peak)
- rate of force development (average and peak)
- ballistic versus non-ballistic movements

To enhance the potential for measuring physiological factors (lower-extremity muscle strength, gait, balance and mobility) the exercises used in an assessment tool should be the same, or as close as reasonably possible, to the transfer characteristics mentioned above (77). Therefore, the more mechanically dissimilar the assessment becomes, the lower the potential for identifying a positive or negative adaptation. For example, the use of a chair rise test to measure lower-extremity muscle strength, although widely used in clinical practice, does not identify which muscle actions have positively or negatively adapted.

1.2.5 Corrective Exercise

The National Academy of Sports Medicine (NASM) in the United States defines corrective exercise as ‘a term used to describe the systematic process of identifying a neuromuscular dysfunction, developing a plan of action and implementing an integrated corrective strategy.’ Several aspects of sedentary living can bring about negative changes to the musculoskeletal system by way of muscle imbalances and movement deficiencies (84). Ironically, higher levels of physical activity and sports participation has also been shown to increase the number of musculoskeletal (MSK) injuries (85). Research has demonstrated that isolated joint/muscle rehabilitation approaches, such as knee extension/flexion exercises, are not sufficient to return a person to ‘normal’ physical performance levels (86-89). Consequently, health professionals are now focussing on the identification of physical impairments and the improvement of movement (movement competency), rather than improving isolated joint/muscle treatments (87, 90).

However, a systematic corrective exercise approach similar to that used by NASM will help address the many factors associated with muscle weakness, flexibility, mobility and movement dysfunction in different environments and populations.

1.2.6 Movement Competency

Movement competency is a term used to describe a person's ability to move optimally during a movement pattern such as rising from a chair. The way a person moves affects muscle activation and in turn determines how the joints of the body are loaded (91-93). Movement competency is a principle that spans a person's life from early childhood through to later adult life, for which independent living is determined in part by an older person's ability to maintain muscle strength, mobility, stability and flexibility to avoid injury and falling (92, 94, 95). Other authors (96, 97) describe movement competency as movement that occurs without pain or discomfort and involves proper joint alignment, muscle coordination and posture. In this thesis, the term 'movement competency' refers to a person's ability to move effectively and efficiently. Human movement will be covered in greater detail in the next chapter.

1.2.7 Measurement of Muscle Strength

Historically, there have been several methods of measuring muscle strength available to the health professional. Manual muscle testing of the lower-extremity commonly takes the form of a patient performing a physical task in a gravity-neutral position, against gravity or against the resistance of the therapist. A score is recorded which is subjective in nature and determined by the experience of the therapists. This score can be quantified using an ordinal scale originally developed by the Medical Research Council (98).

A specific impairment well established as a correlate with fall risk and physical function is lower-extremity muscle weakness (12, 14, 99). The degree to which a muscle is impaired can only be established if the health professional has objective measurement data (absolute and relative). Instrument tests such as isokinetic dynamometry can provide accurate quantitative values on which a patient's performance can be compared. These machines are considered the criterion standard and provide multiple parameters, such as peak force, endurance and are able to generate force curves (100). They also enable precise measurement of muscle strength disparity between raters and subjects, particularly when the subject is stronger than the rater (i.e. during plantar flexion strength testing). However, such equipment is generally very expensive, bulky and non-portable rendering this type of testing protocol inappropriate for large-scale epidemiological studies or clinical practice.

Hand-held dynamometry (HHD) is one solution that has grown in popularity in the clinical setting and can accurately measure strength in most upper and lower-extremity muscle groups (99-102). Thus, HHD can detect muscle strength deficits and imbalances, and aid in the planning of clinical interventions. The validity and reliability of HHD to measure muscle strength in the older adult population has strong support in the literature (103-106). The decision to use HHD in this study is to eliminate the subjectivity of traditional manual muscle testing scoring which is largely dependent on practitioner education and clinical experience (99, 107).

The 'make' and 'break' tests are two measurement techniques used for HHD. The make test involves the rater resisting a maximal isometric contraction, whereas the break test requires the rater to overcome the force of the subject. Lu *et al* (101) examined the reliability of the break test and reported excellent intra-class correlation coefficient (ICC) for all hip and knee muscles (ICC = .83 - .92) except the knee extensors (ICC = .60).

1.3 AIMS & OBJECTIVES

The overall aim of this research is to further develop and examine whether a novel physical assessment tool named the **P**erformance **D**eficit **T**est for **Com**munity-Dwelling older adults (PDT-Com) can detect potentially modifiable physical impairments associated with fall risk in healthy community-dwelling older adults to better direct an exercise intervention programme.

The main population of interest is healthy older adults (>60 years) independently living in the community who have been identified as having a risk of falling either through a routine health screen (self-report), opportunistically (at presentation of a fall) or through accident & emergency departments (with a fall-related injury).

1.3.1 Specific Aims

1) To conduct a **systematic review** of objective muscle strength measurement tools. Specifically, to determine the most appropriate tool for use with community-dwelling older adults.

> Q_1. What tool is valid, reliable and feasible for the objective measurement of lower-extremity muscle strength in this population?

2) To conduct a **systematic review** of multifactorial fall risk assessment tools that have been designed to identify modifiable physical impairments in community-dwelling older adults. Specifically, to investigate the construct and measurement characteristics of tools purporting to assess modifiable physical impairments as risk factors for falling.

> Q_1. Does the data collected by each measurement tool match the abstract constructs that underlie the measures?

Q_2. What are the measurement category differences between assessment tools? This was undertaken by deconstructing the various components of each assessment tool.

3) To conduct a **study to establish reference values** for isometric lower-extremity muscle action force measurements obtained by hand-held dynamometer.

Q_1. What are reference strength values of major muscle groups of the lower-extremity in healthy community-dwelling older men and women?

The extent of a person's muscle strength impairment can be objectively quantified using hand-held dynamometry (HHD) and compared to reference, or normative, values from unimpaired individuals. However, only a few studies have provided reference values for lower-extremity muscle strength obtained by hand-held dynamometry (HHD) in older adults. Such values are essential in quantifying a person's muscle strength impairment.

4) To test the **intra- and inter-rater reliability** of a protocol based on the concept of physical performance tests currently used in elite/professional sport which has been adapted for use on community-dwelling older adults (PDT-Com). Healthy community-dwelling volunteers living in the local area were recruited (n = 30; Aged > 60 years). Specifically, the author wanted to answer the following:

Q_1. Is there consistency of performance among all raters in the assignment of scores to the same subjects?

5) To conduct a **randomised feasibility study** using healthy community-dwelling older adults (n=30; Aged >60 years). Both intervention and control groups were assessed pre-and three-months post-exercise intervention using the PDT-Com, the Timed-Up and Go (TUG), 30s Chair Rise Test (30sCRT) and the Berg Balance Scale (BBS).

Q_1 how does the PDT-Com compare as a measure of physical function to the TUG, BBS and 30sCST?

Q_2 what is the potential effect and feasibility of the PDT-Com and targeted intervention in older adults living in the community compared to the TUG, BBS and 30sCST on three-month post intervention measures?

A secondary research question is as follows:

Q_3 what are participants' perceptions and satisfaction with the PDT-Com assessment procedure and subsequent three-month targeted exercise intervention?

This series of research questions will inform the use of the PDT-Com and subsequent intervention on three-month post-exercise intervention test scores compared with the TUG, BBS and 30sCRT.

1.4 THESIS ORGANISATION

The overarching purpose of this thesis was to further develop an existing subjective physical assessment tool called the 'Performance Deficit Test' (PDT) to be used on healthy community-dwelling older adults. The two main constructs of this tool being a subjective assessment of lower-extremity muscle action strength (manual muscle testing) and an assessment of movement competency. The PDT has been specifically designed for use on a younger more athletic population to identify modifiable injury risk factors but its validity and reliability for use in older adults has not been established.

This thesis addresses this problem as a cohesive whole, and Table 1 outlines the PDT assessment tool status before the start of this research project including what was done during this research project, and Figure 1b illustrates the structure of the separate but inter-related chapters. Chapter 1 outlines the organisational structure of this thesis, rationale, and the aims and objectives, including a discussion of the wider theoretical definitions. Chapters 2 and 3 outline the development of a new assessment tool and scoring system. Chapter 4 discusses the validity of the newly developed assessment tool and Chapter 5 reviews the literature and outlines the current position with regards to epidemiology, fall risk factors, national guidelines, and current assessment approaches used in the study of falls prevention in older adults. Chapter 5 also outlines physical assessments in older adults and discusses topics such as how an objective assessment of transitional movement (squatting, lunging and single leg squatting) may provide insight into an individual's movement strategies. It also explores the theory that purports the use of fundamental movement patterns to identify an individual's movement dysfunction. Chapter 6 presents a systematic review to determine which objective measurement tool is valid and reliable for the measurement of lower-extremity muscle strength in this population. Chapter 7 presents a systematic review of the assessment characteristics of commonly used assessment tools in falls prevention research.

Table 1 - Development of the Performance Deficit Test (PDT) before and during this research project

PDT Developmental Process	Before PhD	During PhD
Develop manual muscle testing protocol (athletic population)	•	
Develop HHD test protocol (adults & older adults)	•	
Development of movement assessment (older adults)	•	
Develop objective scoring criteria (Chapter 8)		•
Examine test-retest reliability of HHD protocol (Chapter 8)		•
Test intra- and inter-rater reliability of the PDT (Chapter 9)		•
Conduct randomised feasibility study (Chapter 10		•

Key: HHD = Hand-held Dynamometer

Chapters 8, 9 and 10 are the experimental studies which feature primary data for the scoring system, intra- and inter-rater reliability, and feasibility testing of the new assessment tool respectively. A full description of the PDT-Com assessment tool and training manual is provided in the appendices (Appendix P). The final chapter consists of conclusions and applied recommendations for health professionals. It makes a series of formal propositions regarding how health professionals may use the new assessment tool to identify dysfunctions in gross fundamental movements and deficits in lower-extremity muscle strength. It also includes directives on how health professionals might use that information to prescribe individualised exercise intervention.

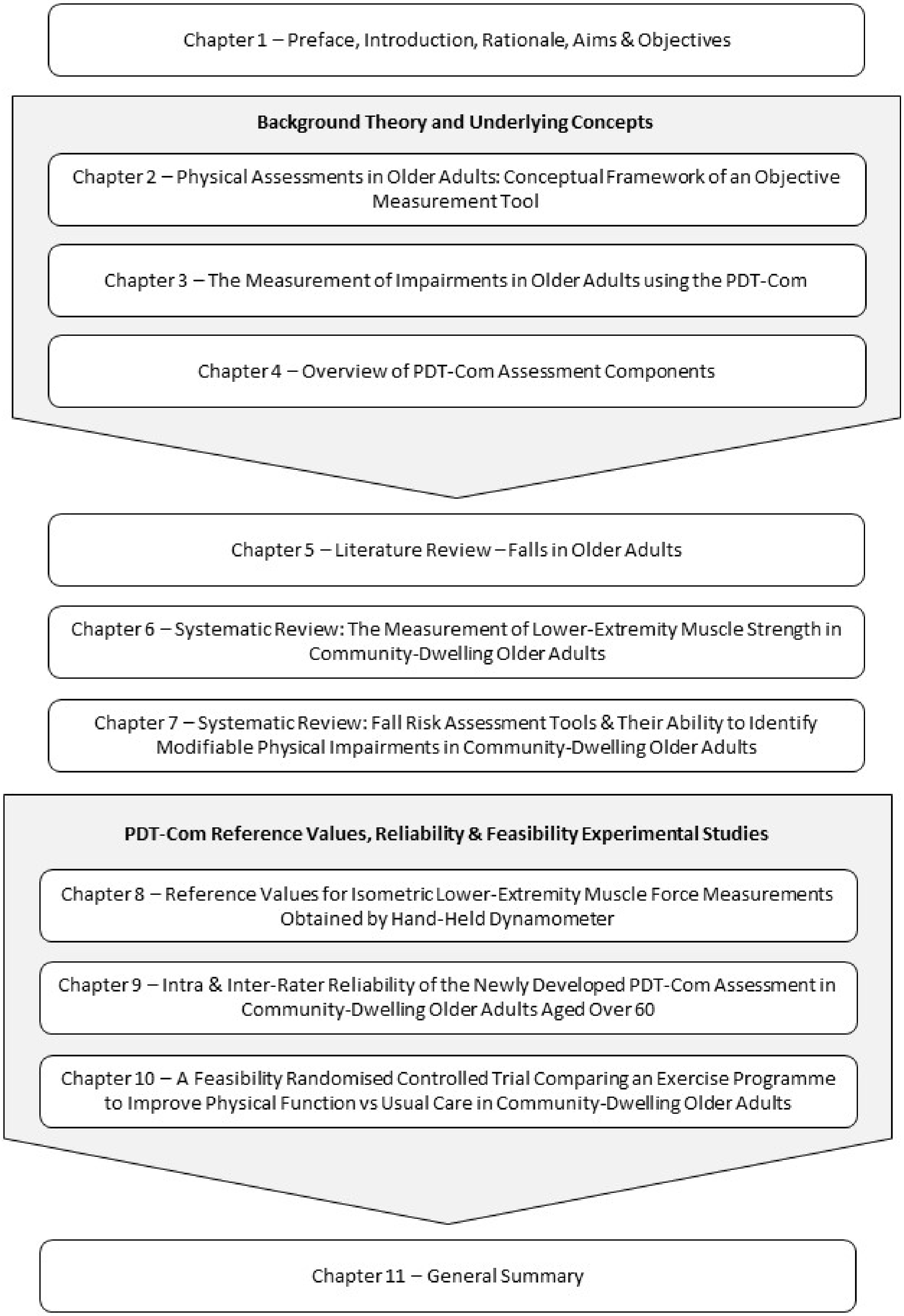


Figure 1. Overview of PhD thesis thematic sections and chapters to investigate a new assessment tool in the identification of modifiable fall risk factors

2 PHYSICAL ASSESSMENT IN OLDER ADULTS: CONCEPTUAL FRAMEWORK OF AN OBJECTIVE MEASUREMENT TOOL

2.1 INTRODUCTION

Functional tests of lower-extremity muscle strength have been widely used in fall prevention research to determine functional status. Tests such as the 30 second chair stand (30sCRT) and Timed-Up-&-Go Test (TUG) have excellent psychometric values and serve to screen people who may be at risk of a future fall. However, the continued use of these tools once risk has been established is questionable because they cannot inform the health professional of the reasons underpinning poor physical performance. Currently, there is no agreed assessment tool with the ability to identify specific muscle strength deficits, balance and gait impairments and other physiological functional limitations and with the ability to use these findings to determine the most appropriate corrective exercise prescription. However, the adaptation of an existing physical function assessment may address these issues. The Performance Deficit Test (PDT) is one such assessment that aims to identify these strength deficits and movement impairments.

This chapter describes the ways in which older adults may experience movement problems and how these can be assessed and measured objectively. Underlying concepts are introduced and explained followed by detailed sections on the squat, lunge and single leg squat movements and their inter-relationships with the lumbopelvic, knee and ankle joints.

2.2 UNDERLYING CONCEPTS

To better understand the health of older adults living in the community, it is important to go beyond current measures of disease and self-perceived health and to use individual assessments of functional status (108). Today, health professionals have access to many assessment tools and equipment as well as to various pre-designed exercise intervention programmes available for use, such as the Falls Management Exercise programme (FaME) (109) and the Otago Home Exercise Programme (OEP) (110). However, the best equipment and exercise interventions cannot improve health and fitness if muscle weakness, dysfunction and impairments are left undetected. The following are considered underlying concepts in the development of a new tool designed to objectively assess physical function and movement competency.

2.2.1 Lower-Extremity Muscle Strength

To achieve optimal movement, lower-extremity muscles need to be activated by the nervous system. A simple definition of strength is 'the ability of the neuromuscular system to generate internal tension to overcome an external force' (84). The ability to accurately and reliably assess muscle strength is a valuable tool for any health professional. Transitional movements such as squatting and lunging involve multiple joints and require muscular force as well as mobility of the hip, knee, and ankle.

Altered movement can affect the length-tension relationships of different muscle groups, reducing the force-generating capacity as a result, and optimum muscle strength and recruitment can only be achieved through the integrated functioning of the skeletal, nervous and muscular systems (84, 96, 97). Coordination in these systems ensures effective muscle balance and strength. However, due to disease, sedentary lifestyles, previous injury and stress, impairments to the human movement system can occur (97), causing altered muscle balance, recruitment and strength (96, 97). Therefore, objective assessment of an individual muscle action's contribution to global transitional movements is a fundamental aspect to direct the corrective exercise part of an individualised intervention.

2.2.2 Maintaining Precise Movement

As with any mechanical system, alignment is important (96, 111). It will be established and discussed in Chapter 6 that alignment of joints during whole-body movements affects lower-extremity muscle activation. Functional activities are performed according to a kinetic chain, a coordinated sequence of motions of body segments, which aims to achieve the desired task in the most efficient position while also considering velocity and timing (84, 112). An advantage of functional testing is that it is thought to replicate the kinematics encountered during a task specific activity (113). Tests of movement are considered useful to gain an insight into the kinematics an individual may exhibit during functional tasks such as transitioning in and out of a chair, walking and stair climbing.

Optimal activation of all body segments in the kinetic chain results in a high strength of control with maximal performance and minimal risk of injury. Assessments that do not measure lower-extremity muscle strength directly can be used to quantify a physical ability without consideration of movement competency or efficiency of underlying functional movement. A good example can be found in an individual who might obtain a good score on the 30sCRT (i.e. >13 seconds) (114) but perform the test inefficiently due to poor alignment of the hip, knee and ankle joints. Compare this person to an individual with an identical 30sCRT score, who performs the test with good joint alignment. Both individuals receive 'above average' scores irrespective of individual movement inefficiencies largely because the test is not designed to distinguish between those with poor and good joint alignment.

2.2.3 Human Movement System Impairments

This section outlines the main types of impairments people have when they move during daily activities and exercise. These impairments may be better understood with an understanding of the anatomy and structures involved in ankle stability/mobility, knee stability and lumbopelvic hip complex instability.

The human movement system is made up of a complex array of interrelated and interdependent myofascial, neuromuscular and articular components. Functional integration of each of these components leads to neuromuscular efficiency during functional activities and activities of daily living (ADL) (84, 96, 111). The optimal alignment and function of all components leads to optimal muscular tension relationships (muscular force), muscular control (nervous system) and optimal arthrokinematics (skeletal system) (96). On account of the integrative nature of the human movement system, impairments are not limited to one structure. Rather, in most cases, Impairment in one system leads to compensation and maladaptation in another (84, 90, 96). These predictable patterns of dysfunction are well documented and referred to as movement impairment syndromes (84, 96).

Ankle Instability

The ankle joint complex is comprised of the lower leg and the foot and forms the kinetic linkage allowing the lower limb to interact with the ground, a key requirement for gait and other activities of daily living (115). The functional structure of the human foot is designed specifically for bipedal locomotion and foot alignment plays an important role in standing posture and walking (116). Despite bearing high compressive and shear forces during gait, the ankle's bony and ligamentous structure enables it to function with a high degree of stability (115). The three main contributors to this stability are the congruity of the articular surfaces when the joints are loaded, the static ligamentous restraints, and finally the musculotendinous units, which allow for dynamic stabilisation of the joints (117). However despite this support, the ankle remains the most commonly injured joint in both daily life and recreational activity (117, 118). One review found a high percentage of patients still experienced pain and subjective instability one-year post injury, while as much as 34% of the patients reported at least one re-sprain within a period of three years (119).

The main bones of the ankle joint are presented in Figure 2. There are three main joints, which are the proximal (closest to centre of body) and distal (away from the centre of the body) tibiofibular joints (articulation between the tibia and fibular), the talocrural joint (articulation between the distal end of the tibia and fibula and the superior surface of the talus), and the subtalar joint (articulations between the inferior surface of the talus and the calcaneus) (115, 120-122).

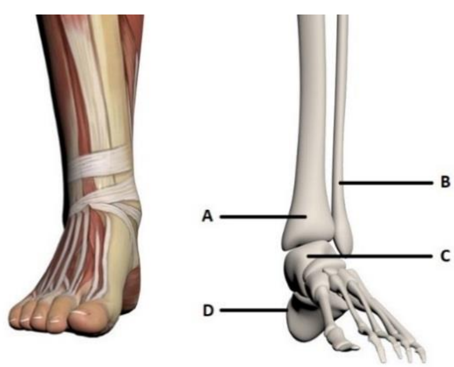


Figure 2 – Bones of the ankle joint (A) Tibia. (B) Fibular. (C) Talus. (D) Calcaneal.

During transitional movements, such as the squat and lunge, the talocrural joint facilitates movement through the actions of dorsiflexion and plantar flexion, whereas the primary action at the subtalar joint is to maintain postural stability and limit eversion/inversion at the foot (120). There are several dysfunctions associated with the foot and ankle joint leading to altered muscle length-tension relationships and joint arthrokinematics (123). Excessive pronation of the foot during exercise has frequently been cited as a risk factor for lower-extremity injury (124), along with previous injury to the lateral ligaments of the ankle (117).

Ankle Mobility

The motions that take place at the ankle joint are plantarflexion and dorsiflexion, which occur in the sagittal plane; abduction/adduction occurring in the transverse plane and inversion/eversion, which occur in the in the frontal plane (Figure 3) (115). Motion of the ankle occurs primarily in the sagittal plane, with plantarflexion and dorsiflexion occurring predominantly at the talocrural joint. Several studies have indicated an overall range of motion (ROM) in the sagittal plane between 65 and 75 degrees, moving from 10 to 20 degrees of dorsiflexion through to 40–55 degrees of plantarflexion (125-127).

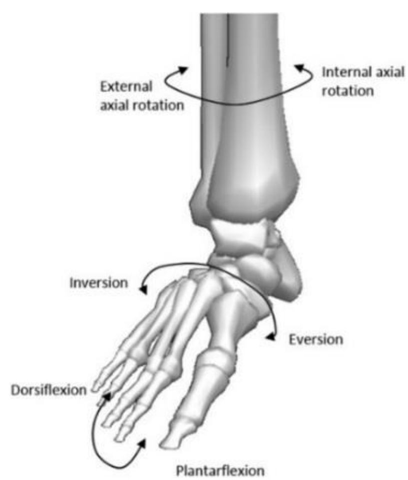


Figure 3 - Diagram illustrating relative motions of the ankle joint complex. Figure adapted from Visual 3D (C-Motion, Rockville, Maryland).

Ankle ROM has been shown to vary significantly between individuals due to geographical and cultural differences based on their activities of daily living (115, 128, 129). For example, squat toilet use, sitting cross-legged, squatting and kneeling on the ground and religious exercises involving kneeling can affect normal ROM of the ankle joints (129). Additionally, age and gender factors have been shown to influence ankle ROM. A study by Nigg *et al.* (130) compared gender differences within different age groups, between 20 and 80 years of age. This demonstrated that younger females (20–39 years) have a higher ankle ROM compared to males. However, with increasing age, older females on average demonstrated 8 degrees less dorsiflexion and 8 degrees greater plantarflexion compared to male patients in the oldest age group (70–79 years), including a reduction in ROM for both genders in the oldest age groups.

Decreases in ankle dorsiflexion have been associated with increased medial knee displacement (valgus) during functional tasks (131). This measurement has been linked to foot compensations (turning outwards, flattening or heels rising) and excessive forward lean of the torso during transitional movements such as a squat into a chair (127). Additionally, restrictions in the gastrocnemius and peroneal muscles may contribute to tibial abduction and external rotation (84, 96, 132), thus, increasing knee valgus. Similarly, the addition of limited posterior talar mobility may limit ankle dorsiflexion (133), and in some cases lead to injury of the knee joint (123). Other factors affecting ROM in the ankle are previous lateral ankle sprains (117, 133), osteoarthritis (134-137), and total joint replacement surgery (134, 135, 137-140).

Knee Stability

The knee joint is greatly affected by the linked structures of the ankle and lumbopelvic hip complex (LPHC). The foot, ankle and LPHC play a major role in reducing knee joint impairments because these same structures make up the knee joint (84). Stability is maintained by the shape of the condyles (a rounded protuberance at the end of some bones, forming an articulation with another bone) and menisci (cartilage between the join space that protects and cushions the joint) together with passive supporting structures (141). Stability during transitional movements is an important factor to reduce injuries of the lower-extremity in active populations (131).

The knee joint is one of the largest joints in the human body and is considered a modified hinge joint consisting the tibiofemoral (tibia and femur) and patellofemoral (patella and femur) joints (Figure 4). It is situated between the ankle joint (proximal) and lumbopelvic hip complex (distal) and is shown in Figure 5 (142). The knee flexes posteriorly and extends in the anterior direction (84, 121). It is considered a stable joint because of its ligament and tendon arrangement and limited hinge movement in the anteroposterior direction (96, 142, 143).

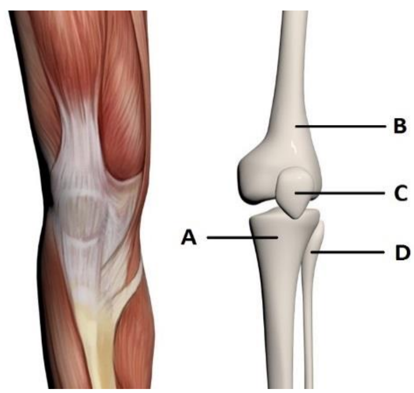


Figure 4 - Bones of the knee joint (A) Tibia. (B) Femur. (C) Patella. (D) Fibular

The knee is supported by several ligaments which are the main stabilisers during static conditions (143), whereas the knee musculature acting over the joint assumes the dominant role in dynamic joint stabilisation such as during squatting and lunging (141, 144). It is therefore important to restore normal range of motion, muscle activation and strength to ensure the knee joint operates optimally (84).

The iliofemoral and talocrural joints relating to the knee help stabilise the knee joint through proper alignment and muscular function. Consequently, the knee joint may become unstable if these proximal and distal joints are dysfunctional (84, 96, 145). It is well documented that excessive compressive (push together) and sheer (resistance to sliding) forces can damage ligament and cartilage structures of the knee joint because of faulty joint alignment (142, 146). One explanation for lower-extremity alignment issues has been faulty structure and function of the hip and distal ankle joints (91, 92, 94, 142, 147, 148).

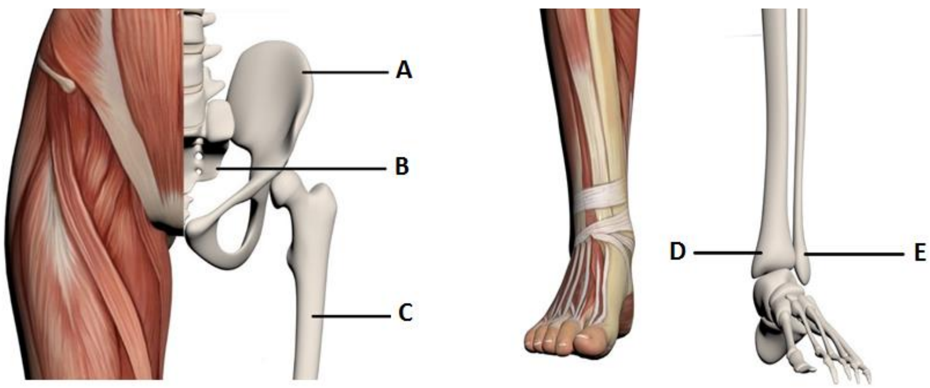


Figure 5 – Proximal and distal bones affecting the knee joint (A) Ilium. (B) Sacrum. (C) Femur. (D) Tibia. (E) Fibular.

The hamstrings and quadriceps muscles, which attach to both the lumbopelvic hip complex and knee, as well as the gastrocnemius which attaches to both the knee and ankle joints predispose the knee joint to excessive forces if they are weak, inhibited, underdeveloped or activated in the wrong sequence (84, 96). Furthermore, decreased mediolateral neuromuscular control (ligament dominance), quadriceps dominance (overactivity coupled with underactivity of the hamstrings), and leg dominance (unequal loading of one leg) are all considered major contributors to knee instability in females (92, 149). Two commonly reported transitional movement dysfunctions of the knee are excessive medial knee translation (valgus) observed from the front (Figure 6a) and excessive anterior motion observed from the side (Figure 6b) (147, 150).

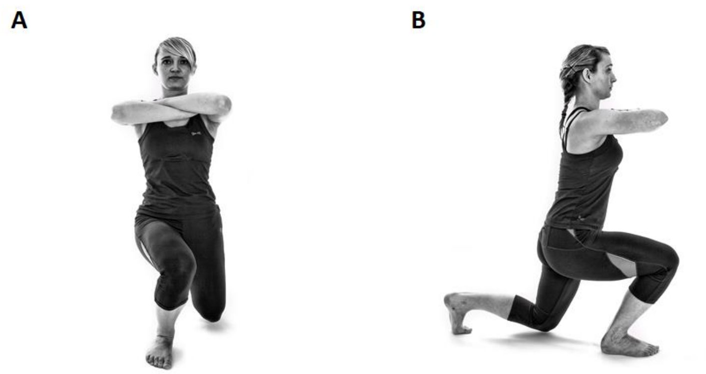


Figure 6 – (A) Excessive medial knee translation (valgus) and (B) excessive anterior motion.

Lumbopelvic Hip Complex Instability

The lumbopelvic hip complex (LPHC) is composed of the lumbar vertebrae, the pelvis, the hip joints, and the active and passive structures that either produce or restrict movement of these segments (151). Health professionals often refer to this region as the 'core' or 'mid-section. The stability of any system is the ability to limit displacement and maintain structural integrity. Stability of the LPHC is necessary to maintain the integrity of the spinal column to furnish a stable base for movement of the extremities, and most importantly to provide resistance to perturbations. Thus, the primary contribution of the active muscular elements of the mid-section to LPHC stability is to increase stiffness of the hip and trunk.

The main muscles of the LPHC that function in the sagittal plane are illustrated in Figure 7. These include the rectus abdominus, transverse abdominus, erector spinae, multifidus, gluteus maximus and hamstrings (151, 152). Of these muscles, the gluteus maximus is important in the transfer of force from the lower-extremity to the trunk (151). Muscles that function in the frontal plane are the gluteus medius, gluteus minimus and the quadratus lumborum and these work together to maintain a stable pelvis during movement. Frontal plane muscles of the LPHC are the adductors (magnus, longus and brevis). Their role in pelvic stabilisation is less than their lateral counterparts due to not having to counteract large internal femoral rotation forces during single-leg movements (151). Several authors have investigated the contribution of individual muscles to stability of the LPHC. However, it has been shown that no one particular muscle contributes more than 30% of the overall stability of the lumbar spine (152).

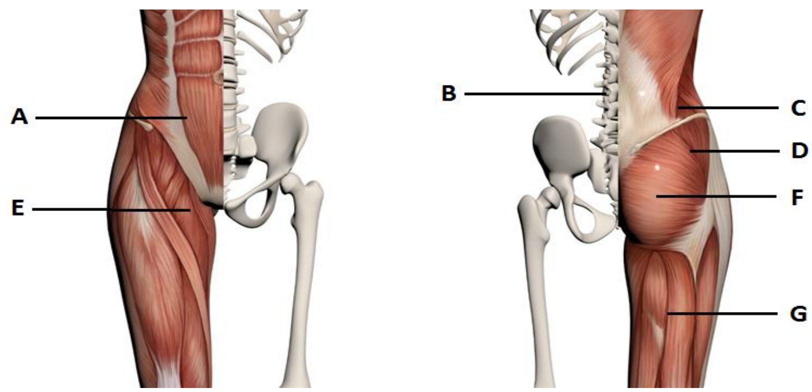


Figure 7 – Main musculature of the lumbopelvic hip complex. (A) Rectus Abdominus. (B) Multifidus. (C) Quadratus Lumborum. (D) Gluteus Medius. (E) Adductors. (F) Gluteus Maximus. (G) Hamstrings.

The musculature of the LPHC is important in lower–extremity physical performance and joint alignment during transitional movements. An individuals' ability to demonstrate LPHC stability is determined through a complex relationship between hip and trunk muscle capacity and motor control (151). It has been demonstrated that weakness of the active muscular elements of the LPHC, particularly in transverse and frontal planes (tilting and rotation respectively), may contribute to altered alignment of the knee and ankle joints (123) (Figure 8). There is also a strong association with increased movement (extension and flexion) of the LPHC with excessive foot/ankle pronation and increased medial knee displacement (valgus) (84, 151). Furthermore, without proper recruitment of the large hip extensor musculature (gluteals and hamstrings), other muscle groups such as the quadriceps compensate through excessive loading. This in turn causes sub-optimal muscle recruitment patterns leading to muscle imbalance and increased risk of injury (94).

Figure 8 – Single leg squat test demonstrating femoral internal rotation, excessive knee medial translation (valgus), and ankle pronation.

2.3 ASSESSMENT OF MOVEMENTS: THE SQUAT

A squat can be described as flexing at the hip and knee joints and descending until the top part of the thigh at the hip joint is lower than the knee joint, then ascending by extending the knee and hip joints to return to the start position. The foot, ankle, knee, hip and the lumbar and thoracic spine of the upper body require sufficient stability and mobility to create a competent squat pattern (96). The squat movement has close specificity to many every-day tasks, such as lifting bags and rising from a chair, as well as having an indirect contribution to a plethora of other daily physical tasks (e.g. sitting and rising from a chair, hobbies and recreational activities). During bodyweight squatting, authors have reported shear forces like that experienced during walking (1 -1.5 times body weight) and patellofemoral forces similar to ground reaction forces experienced during running and landing (4 – 5 times body weight) (121, 142, 153). The squat also is widely used in a clinical setting to strengthen the muscles and connective tissues of the lower-extremity following injury (94, 149, 154), and to maintain mobility of the hip, knee and ankle due to the multi-joint nature of the movement (143, 155).

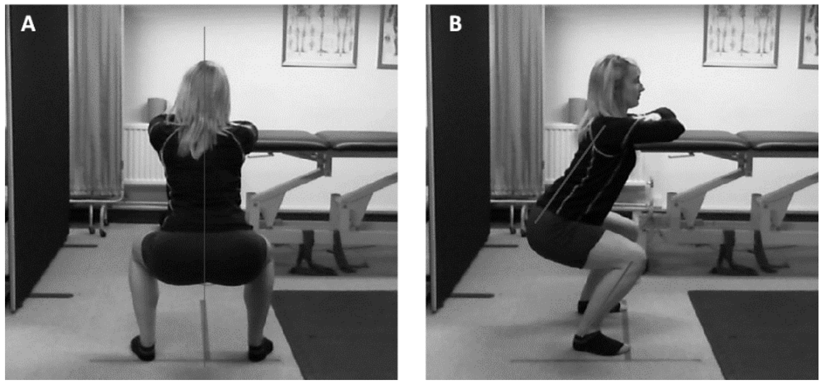


Figure 9 – The bodyweight squat showing good alignment from the rear (A) and front views (B).

Much research has been dedicated to establish the squat as an effective movement to improve athletic performance (156), but little is known about how the bodyweight squat pattern can be used to establish a person's movement competency. Prominent American physical therapist Gray Cook describes the ability to squat at 90 degrees of knee flexion with balance, control and symmetry as an indicator of overall movement ability (145), while several others propose the squat to be a good indicator of movement dysfunction (94, 121, 157). Despite many individual variations on the instruction and execution of the squat to elicit a desired adaptation, there is a fundamental model or blueprint that underlines the biomechanical technique for positive adaptations for physical performance and injury risk reduction (94). This section describes and discusses what has been reported in the literature to be correct kinematics (movement) for the bodyweight squat.

2.3.1 Ankle joint position

The ability to maintain a neutral foot and ankle position during the bodyweight squat ensures a balanced and controlled movement (94). Several factors may limit one's squatting ability, such as reduced ankle dorsiflexion (145, 155, 158), ankle stiffness (145) and lower-limb muscle weakness (123, 150, 159). Furthermore, proximal factors such as LPHC weakness may also contribute to a lack of ankle joint stability during squatting, leading to excessive ankle pronation (84, 123, 150) (Figure 10).

To perform a good squat, it is proposed that a person's feet are stable and planted firmly on the ground (94). Many authors recommend heel width to be either between hip and shoulder (160) or shoulder width apart or more (161-164). In some instances, no recommendation for stance width is indicated (94, 157, 162). Interestingly, it has been shown that stance width (75 – 140% shoulder width) has no noticeable effects on muscle activation in the lower-extremity (142, 165). Most authors recommend limiting the foot to 30 degrees of external rotation (turning outwards), and to avoid excessive eversion (pronation) during squatting movements.

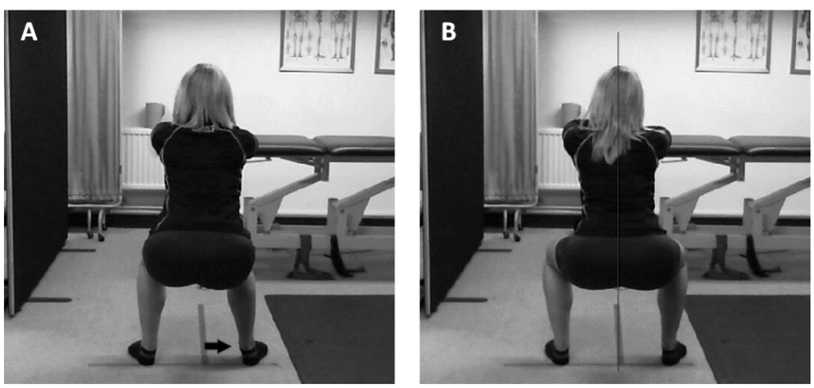


Figure 10 – The bodyweight squat showing (A) excessive ankle pronation and knee valgus and (B) correct alignment.

2.3.2 Knee joint position

To perform an effective squat, it is proposed that the knees should track over the toes with an absence of lateral (varus) and medial (valgus) knee displacement. Knee joint malalignment through excessive medial displacement during a bodyweight squat signals a functional deficit (84, 96, 123, 159, 166).

As a result, authors have suggested a neutral knee alignment to be desirable during squatting (Figure 11b).

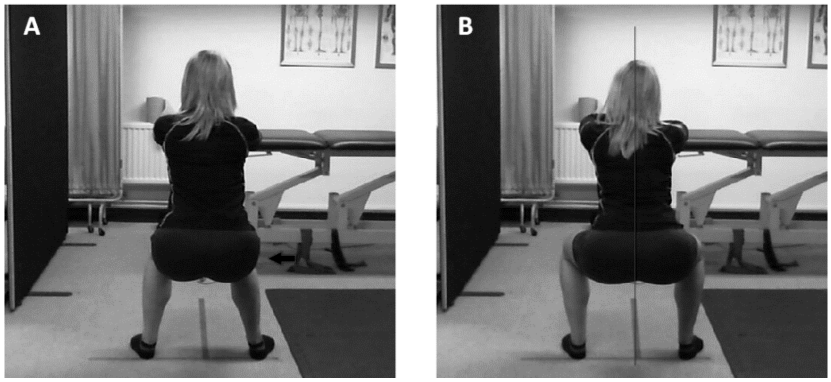


Figure 11 – The bodyweight squat showing (A) incorrect (valgus) knee position and (B) correct knee position.

Excessive anterior motion of the knee during the squat is another commonly observed compensatory movement pattern. As a general rule, increased anterior tibial translation increases torque about the knee joint (147). However, there is no evidence to suggest that these forces increase a person's risk of knee injury (147). Thus, if the heels remain firmly in contact with the ground, and no forward lean of the trunk is observed, anterior tibial translation should not be discouraged (Figure 9b). An increase in the forward lean of the trunk has been reported to increase the forces experienced by the lumbar spine (147). Increased forces experienced by the lumbar spine during squatting should not be considered a contraindication unless the LPHC is unable to maintain a stable position during the movement task (121).

2.3.3 The Lumbopelvic Hip Complex (LPHC)

Dysfunction and/or compensation observed in the LPHC region can lead to dysfunction elsewhere in the body (96, 150, 167, 168). Evidence suggests that maintaining a neutral lumbar spine position during a squat ensures optimal muscular support for the spine (94).

Dysfunctional movement strategies adopted to improve squat depth include tilting the pelvis posteriorly, asymmetrical weight shift (Figure 12a), and rounding the lower and/or middle back area (Figure 16b) (94, 96, 121). However, these strategies are discouraged due to significant stress placed on the lumbar region of the spine (96, 121).

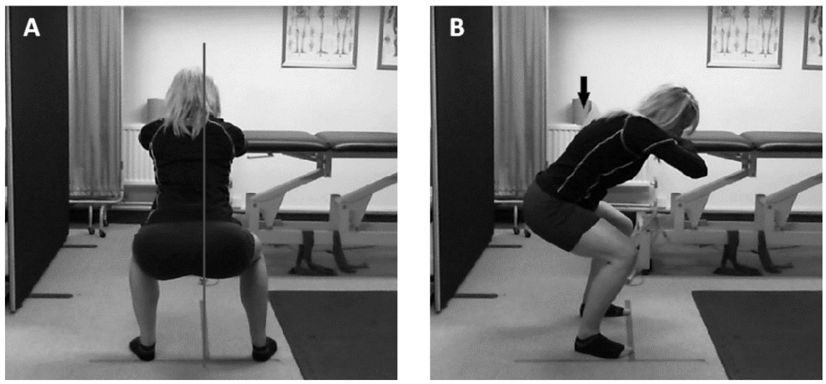


Figure 12 – The bodyweight squat showing (A) asymmetric weight shift and (B) excessive thoracic spine rounding

The LPHC will be required to move more if the ankle joint is restricted, resulting in excessive forward flexion to regain balance (Figure 12b) (96, 147). To perform a good squat, the lumbar vertebrae are maintained in neutral alignment throughout the movement. In practice, this entails maintaining a natural lordotic curve while holding the abdomen upward and rigid to promote stability (94) (Figure 13a).

2.3.4 The Trunk

A trunk that is unsteady and moves forward during the squat may be indicative of a general weakness of the LPHC. Furthermore, the squat requires adequate spinal mobility to maintain neutral lumbar positioning (94). According to researchers, a demonstration of trunk stability and control during a bodyweight squat is keeping a constant angle of the trunk during the descent and ascent (94, 121, 160).

The trunk should remain stable throughout the squat movement with no observation of anterior displacement (Figure 13a), and/or excessive trunk flexion (Figure 13b). Several authors suggest the forward angle of the trunk is similar to the tibial angle from a lateral perspective during squatting (Figure 13a) (121).

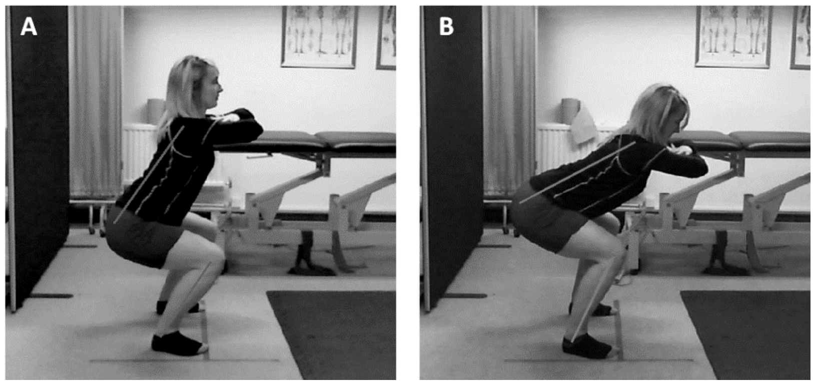


Figure 13 – The bodyweight squat showing (A) correct trunk position and (B) excessive forward lean.

2.3.5 Summary

A foundational understanding of the kinematics and kinetics of ankle, knee, LPHC and thoracic spine during a bodyweight squat has been provided. Compensatory movements that promote joint malalignment and poor body position may increase the compressive and shear forces in these areas. It appears that a simple bodyweight squat gives useful information that may give insights into movement deficits. Table 2 summarises what the literature has reported to be proper position of each body segment and joint during the descent and ascent phases for the bodyweight squat.

Table 2 - Kinematic considerations of the bodyweight squat

Anatomical Region	Kritz (121)	Myer (94)	McKeown (169)	Summary
Head & Neck	Neutral	Neutral to slight extension	Neutral	Neutral
Thoracic Spine	Slightly extended	Slightly extended	Neutral	Slightly extended
Lumbar Spine	Neutral	Neutral	Neutral	Neutral
Hip Joint	Flexed	Flexed and square	Square and stable	Flexed, square and stable
Knees	Aligned with foot	Track over the toes	Perfect Alignment of knee and foot	Aligned with feet
Foot & Ankle	Shoulder width and flat	Stable and firmly on the ground	Not reported	Shoulder width and flat

2.4 ASSESSMENT OF MOVEMENTS: THE FORWARD LUNGE

The forward lunge (FL) appears to be a hip-extensor–dominant exercise with nearly equal relative ankle and knee contributions at lower external loads (170, 171). These findings do not suggest that the quadriceps muscles are not contributors to the lunge movement, rather the hip extensors provide a greater contribution to the total force required. In addition, as external loads increased, mechanical work increased for the hip and ankle but did not change for the knee. Therefore, if the ability to lunge effectively is more reliant on the muscles of the hip, this has wide ranging implications of the importance of the quadriceps muscles in functional movement competency. The multiple joint characteristics of the FL make it a useful assessment tool for identifying dysfunctional movement strategies. Because the lunge allows for unequal distribution of physical demands on the ankle, knee and LPHC, it is considered a suitable intervention to target unilateral muscle strength deficits (171). For example, if an older adult if found to have hip extensor weakness on one side, the FL can be utilised as part of a targeted exercise intervention programme to restore this imbalance.

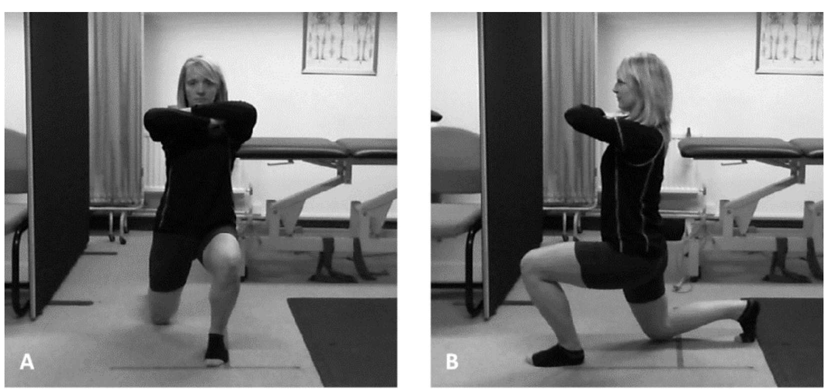


Figure 14 – The forward lunge viewed from the front (A) and the side (B).

Considering the relevance of the FL to completing certain daily physical tasks, and its ease of application as a test, the inclusion of the FL in an assessment battery may have many benefits.

Several authors have proposed what they consider to be correct FL technique criteria (Table 3). Figure 18 illustrates a FL demonstrating good alignment, stability, mobility and balance. This section describes and discusses what has been reported in the literature to be correct kinematics (movement) for the FL.

2.4.1 The Ankle Joint

Like the squat, several factors may limit one's FL ability. During performance of the movement, the lead ankle joint needs sufficient lateral stability and mobility to ensure a correct lunge pattern is achieved (145, 169, 172). Ankle mobility is crucial to accommodate good movement during a lunge (145). Reduced ankle dorsiflexion has been associated with excessive pronation of the foot (84), altered dynamic movement strategies (96, 173) and ankle ligament injuries (84, 117). If the foot excessively pronates during dynamic movements, the lower-extremity will alter motion accordingly (84). Furthermore, it appears that excessive foot pronation may influence lower-extremity muscle activation and strength, and that correction of pronation can positively alter muscle activation (117, 174).

To perform a good FL, it is proposed that the lead foot is not turned outwards and that it remains firmly on the floor during full hip and knee flexion, while avoiding excessive pronation (Figure 14).

2.4.2 The Knee Joint

Control of the knee joint during a FL is needed to counteract mediolateral (valgus and varus) and anteroposterior (forwards and backwards) movements (Figure 15). Some authors state the knee joint is not designed to accommodate these excessive shear forces (142), and avoidance is recommended to reduce risk injury (96, 145).

Additionally, excessive forward motion of the knee over the lead foot has been reported to increase patellofemoral shear forces, leading to knee pain in active populations (92, 123, 175, 176).

Figure 15 – The bodyweight forward lunge showing excessive knee mediolateral movement (valgus)

Although there is disagreement between researchers about the causes of knee injuries in relation to poor knee control, mediolateral and anteroposterior movement during the ascent and descent phases of lower-extremity exercises is contraindicated (142, 172). Weakness, underdeveloped or delayed activation of the hip extensors (glutes and hamstrings), adductors and/or quadriceps have been reported as contributors to poor movement during a FL (177).

To perform a good FL, it is proposed that the knee is vertically aligned with the foot and ankle when viewed from the front (Figure 14a). When observing from the side view, the knee should move forward towards the toes with the heel remaining firmly on the floor (Figure 16).

2.4.3 The Lumbopelvic Hip Complex in the Forward Lunge

Like the squat, stability of the LPHC is required to perform a proper FL. Hip range of movement is considerable and excessive forward lean or extension can increase forces in this region by 30% (178).

Researchers suggest the LPHC should remain parallel (horizontally aligned) to the ground (145, 172), with no mediolateral rotation or dropping of the hip (145, 172, 179). In addition, excessive lumbar extension is not recommended because of increases in compressive forces (173).

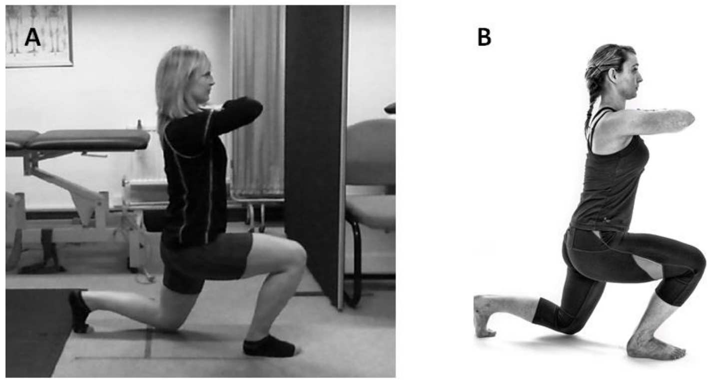


Figure 16 – The bodyweight forward lunge showing (A) upright trunk, and (B) forward trunk position.

2.4.4 The Trunk

The trunk should remain upright (vertically aligned) with the LPHC with the spine in a neutral position. However, greater muscle recruitment of the hip extensors has been shown when the trunk is flexed forward compared to erect (178). Therefore, performing a FL with the trunk forward may be desirable when the goal is to increase recruitment of the hip extensors (Figure 16b). Furthermore, a demonstration of trunk stability and control during a bodyweight lunge is by maintaining a neutral or slightly extended thoracic spine alignment and keeping the shoulders over the hips (145, 172, 179).

2.4.5 Summary

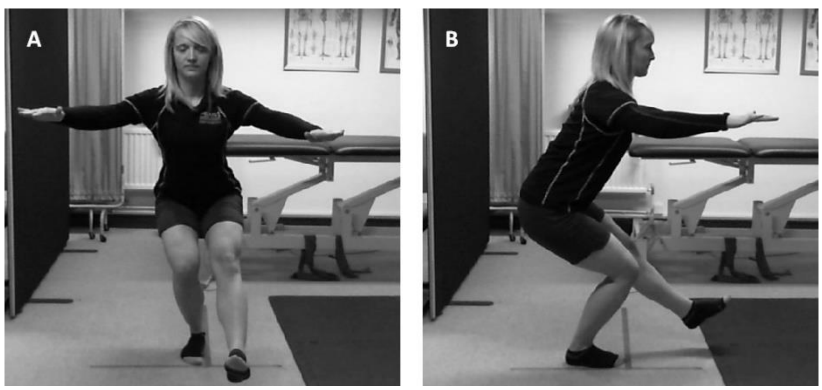
A foundational understanding of the kinematics and kinetics of ankle, knee, LPHC and thoracic spine during a lunge movement has been provided. This movement is considered a functional test similar to activities of daily living such as picking items off the floor. It appears that a simple bodyweight lunge may be used to better understand the movement strategy of older adults. To perform a lunge movement correctly, the trunk must remain stable with appropriate mobility present at the hips and ankles to support knee stability. Table 3 summarises what the literature has reported to be proper position of each body segment and joint during the descent and ascent phases of a lunge.

Table 3 - Kinematic considerations of the bodyweight forward lunge

Anatomical Region	Kritz (121)	Cook (157)	McKeown (169)	Graham (179)	Summary
Head & Neck	Straight and centrally aligned	Centrally positioned	Not reported	Erect facing forwards	Straight and centrally aligned
Thoracic Spine	Straight or slightly extended	Straight	Neutral spine	Erect, shoulders above hips	Straight or slightly extended
Lumbar Spine	Neutral	Neutral	Neutral	Erect	Neutral
Hip Joint	Horizontally aligned	Horizontally aligned	Perfect alignment	Aligned with lead knee/ankle	Horizontally aligned
Knees	Front knee aligned with toes and over lead ankle	Aligned with hip and foot	Perfect control and alignment	Front knee over lead ankle	Front knee aligned with foot
Foot & Ankle	Front foot flat, rear on ball of foot. Both feet aligned and balanced	Front and rear foot alignment (in-line)	Perfect control and alignment	Front foot flat, back on ball of the foot	Front foot flat and stable, back foot on ball of the foot

2.5 ASSESSMENT OF MOVEMENTS: THE SINGLE LEG SQUAT

Since its development as a clinical test the single leg squat (SLSQ) has been performed in a variety of ways in different research settings (180). These involve hip and knee flexion and although similar, they have differences in protocols that are likely to present different movement challenges. The landmark work of Livengood is considered the standard for the leg squat method and interpretation (181). However, several studies either fail to describe the method for testing (182-184), incorrectly describe the method (16) or develop their own method (185, 186), making



comparisons between studies difficult.

Figure 17 – The SLSQ showing good alignment from the front (A) and side views (B).

In general, participants are instructed to stand on one leg, either with arms placed on the hips (84, 90), crossed over the chest (187, 188), or out in front (173), squat down as far as possible (187-189) or to an approximate degree of knee flexion (173, 186, 190, 191), and to return to the initial position (Figure 17). Details of the positioning of the non-stance leg (i.e. the leg not in contact with the floor) are generally not reported. However, it has been suggested that the non-stance leg is better placed behind the body when assessing more athletic populations as this simulates an athletic position (192). Given the extensive use of the SLSQ within the literature for functional assessment, injury prevention and rehabilitation, this section provides a summary of the recommended screening criteria for the SLSQ.

2.5.1 The Ankle Joint in the single leg squat

Because the SLSQ test was originally developed to establish the extent of medial knee displacement, the foot and ankle joints have received little attention in the literature. However, like the squat, the ability to maintain a neutral foot and ankle position during a SLSQ ensures a balanced and controlled movement (94). It is recommended that the foot of the stance leg remains in contact with the ground and remains in a neutral position so that there is no observed pronation, eversion or plantarflexion (84, 193). The limiting factors are the same as for the squat movement detailed in the previous section. It has been shown that excessive pronation of the foot during weight-bearing causes altered alignment of the tibia, femur and LPHC (Figure 18a) leading to unwanted compressive joint forces and potential soft tissue damage (175).

2.5.2 The Knee Joint position during the single leg squat

The position of the knee during transitional movements has received much attention in the literature and its alignment has already been discussed in the previous sections. Excessive mediolateral frontal and transverse plane motion of the knee during a close chain unilateral lower limb assessment is an indicator of poor lower limb neuromuscular control and strength (Figure 18a) (84, 90, 91, 96, 149, 194). A key component of the SLSQ assessment is alignment of the knee relative to the foot in the frontal plane. A clinical measure of knee control is an observation of the position of the patella relative to a line extending vertically from the 1st or 2nd toes (90, 159).

Some authors argue that during closed chain dynamic movements the knee should remain vertically aligned with the foot through various degrees of knee flexion, and should not travel excessively in front of the toes (84, 147).

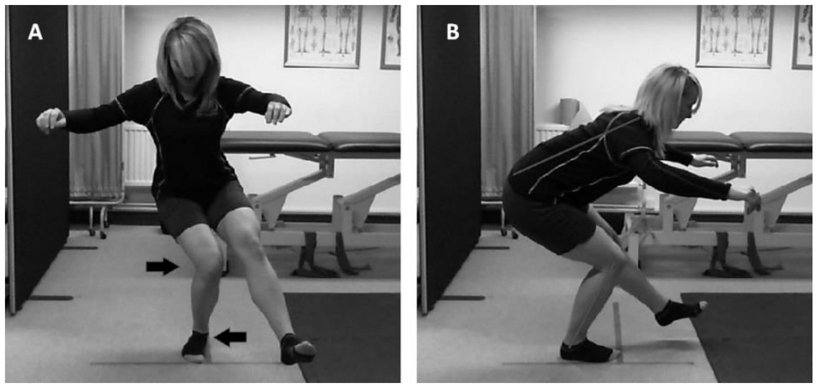


Figure 18 – The SLSQ showing (A) excessive medial knee displacement (valgus) and foot/ankle pronation and (B) excessive trunk flexion.

2.5.3 The Lumbopelvic Hip Complex during the single leg squat

Deficits in neuromuscular control of the LPHC may lead to uncontrolled trunk displacement during functional tasks, which in turn place the knee in a valgus position (90, 195, 196), causing excessive foot/ankle pronation (158), and in the longer term, maypotentially trigger vertebral disc problems (96, 173). Therefore, it is proposed that the lumbar spine should not flex excessively (Figure 18b) during the descent due to unwanted forces affecting the lumbar discs (84, 96, 172).

2.5.4 The Trunk position during the single leg squat

The angle of the trunk in relation to the ground should remain constant throughout the descent and ascent phases of the SLSQ in order to demonstrate stability and control (Figure 17b) (96).

The thoracic spine should have suitable mobility to remain in a neutral position (i.e. slightly extended) with none of the lateral movement or twisting illustrated in Figure 19 (84, 96).

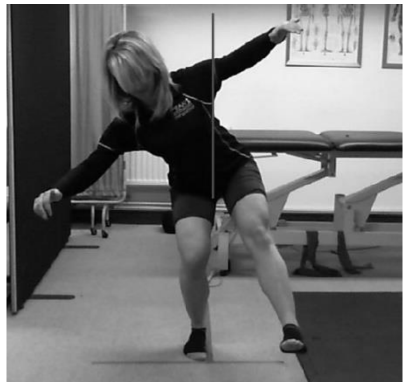


Figure 19 – The SLSQ showing excessive lateral movement of the trunk

2.5.5 Summary

A foundational understanding of the kinematics and kinetics of ankle, knee, LPHC and thoracic spine during the SLSQ has been provided. The SLSQ is a common assessment tool used in clinical, field and rehabilitation environments. Table 4 summarises the correct position of each body segment and joint during the descent and ascent phases for the bodyweight SLSQ according to available literature.

Table 4 **-** Kinematic considerations of the bodyweight single leg squat

Anatomical Region	Livengood (181)	McGill (173)	NASM (84)	McKeown (169)	Summary
Head & Neck	Not reported	Neutral	Neutral	Not reported	Neutral
Thoracic Spine	Not reported	Stiff	Not reported	Perfect posture	Neutral
Lumbar Spine	Not reported	Neutral	Neutral / straight and level	Neutral	Neutral / straight and level
Hip Joint	Not reported	Neutral	Not reported	Neutral	Flexed and level
Knees	<10 degrees valgus	Not reported	In-line with foot	Perfect alignment	In line with foot
Foot & Ankle	Not reported	Not reported	Straight ahead and neutral	Not reported	Straight ahead and neutral ankle

2.6 CHAPTER SUMMARY

This chapter has described the underlying conceptual framework and introduced some examples of where older adults may experience movement problems. It has also been postulated how these movements can be assessed and measured objectively in high functioning community-dwelling older adults. The PDT assessment is designed to identify strength deficits and movement impairments as they are determinants for the maintenance of physical function. It proposes the use of objective measures of lower-extremity muscle strength using hand-held dynamometry and using three simple bodyweight transitional movements (the squat, the forward lunge and the single leg squat) to better understand the muscle strength and movement strategy of an adult prior to the prescription of an exercise intervention. It also proposes that health professionals may benefit from using these functional performance tests to assist in the design of exercise interventions, and to ensure that their adaptations contribute to an increase in physical performance rather than injury or an increase in risk of falling.

3 THE MEASUREMENT OF IMPAIRMENTS IN OLDER ADULTS USING THE PDT-COM

3.1 INTRODUCTION

This chapter outlines and describes the PDT-Com assessment measurements and its scoring criteria. An explanation of each element is given and the reasons for inclusion. This chapter also outlines and describes the output results graph and possible interpretations. For the development of physical competency and the maintenance of independence, the aim is to identify and eradicate any physiological limitations. With the assistance of a suitable scoring criteria, it is possible to create a physical competency journey where progressive assessment stages create a continuum of physical development.

3.2 ASSESSMENT OF MOVEMENT COMPETENCY

The gold standard for assessing kinematics during dynamic tasks is by three-dimensional (3D) motion analysis (197, 198). However, it is widely acknowledged these detailed analyses present considerable financial, spatial, and time costs, which may severely limit their application in studies involving large-scale population screening and evaluation. Altogether the concerns raised by 3D analysis have encouraged researchers, clinicians and exercise specialists to formulate other simpler but acceptably reliable and valid measures of movement impairments linked to physical function (84, 96, 157, 169, 181, 195, 199-201).

The PDT-Com is an objective assessment tool that was originally developed before this PhD and has since been refined, and tested during this doctoral research project. The tool was designed specifically to identify impairments during transitional movements in an older adult population. The PDT-Com movement competency assessments are taken from the original subjective PDT protocol which consisted of observing gross transitional movement patterns in athletic populations based on human movement system principles (96).

For the movement section of the PTD-Com, only the forward lunge movement has been modified from the original PDT assessment by reducing the required knee joint angle to 90 degrees of flexion to avoid a potential floor effect.

Movements for the squat, forward lunge and single leg-squat (SLSQ) are scored on a 1-6 ordinal scale (Figures 20-22). All movement assessments are performed without footwear or external balance support. However, a chair, medical couch or wall can be used if the older adult is frail or unsteady on their feet. Each movement is repeated three times and a score is recorded based on the type of movement dysfunctions observed by the rater. A dysfunctional movement can be identified bilaterally or unilaterally (Table 5).

Table 5 - PDT-Com transitional movements and associated dysfunctions

Dysfunction	**Squat**	**Forward Lunge**	**Single leg squat**
Ankle Pronation	•	•	•
Knee Valgus	•	•	•
Lateral Hip Shift	•	•	
Trunk Alignment (Sagittal)	•	•	•
Knee Flexion <90^{o}	•	•	•
Lumbar/Thoracic Flexion	•		
Trunk Alignment (Frontal)		•	•
Loss of Balance			•

The Functional Movement Screen, Athletic Ability Assessment, Landing Error Scoring System, Star Excursion Balance Test and Balance Error Scoring System are examples of real-time movement competency assessments that have demonstrated good reliability in younger athletic populations (169, 200, 202, 203).

The PDT-Com score for each transitional movement is quantified using an ordinal scale based on observation of several dysfunctions. The movement composite score is quantified as the sum of 18 possible individual movement errors across three transitional movements (Table 5). The PDT-Com score is simply calculated by observation of specific movement dysfunctions during each transitional movement. For example, when performing a squat movement, if a subject presents with all the listed dysfunctions, they would be assigned a score of 1. However, if ankle pronation or knee valgus was observed then that subject would be assigned a score of 4 (see Figure 20). Operationally, the PDT-Com movements can either be scored in real time or video-recorded (with consent) to enable the clinician to retrospectively score each subject at a later time/date. This latter method can be particularly useful if several subjects are being tested or time is limited.

A limitation of the PDT movement composite score is that all identified movement errors are grouped into a single overall score, which could comprise any combination of individual specific movement errors.

3.2.1 Scoring Criteria for the Squat

PDT Scoring Criteria - Squats			
Rear View			
Sagittal View			
Score	**1**	**2**	**3**
Criteria	• Ankle Pronation • Knee valgus • Knee flexion <90 degrees • Lateral shift • Lumbar/thoracic flexion • Poor sagittal trunk alignment	• Ankle pronation • Knee valgus • Knee Flexion <90 degrees + • Any other observed dysfunctions	• Ankle pronation • Knee valgus + • Any other observed dysfunction
Rear View			
Sagittal View			
Score	**4**	**5**	**6**
Criteria	• Ankle pronation OR • Knee valgus + • Any other observed dysfunction	• Any observed dysfunction (x 1)	• No observed dysfunctions

Figure 20 – PDT-Com scoring criteria for the squat showing rear and sagittal view examples

3.2.2 Scoring Criteria for the Forward Lunge

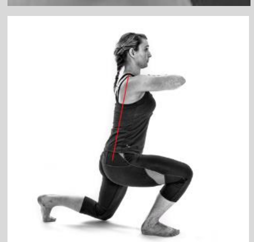
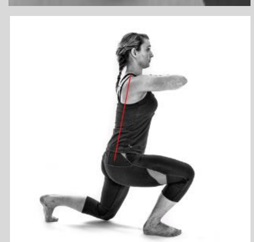
PDT Scoring Criteria - Lunge			
Frontal View			
Sagittal View			
Score	**1**	**2**	**3**
Criteria	• Ankle Pronation • Lateral hip shift • Knee valgus • Poor sagittal trunk alignment • Front knee flexion <90 degrees • Poor frontal trunk alignment	• Ankle pronation • Lateral Hip Shift • Knee Flexion <90 degrees + • Any other observed dysfunctions	• Ankle pronation • Lateral hip shift + Any other observed dysfunction
Frontal View			
Sagittal View			
Score	**4**	**5**	**6**
Criteria	• Ankle pronation OR • Lateral Hip Shift + Any other observed dysfunctions	• Any observed dysfunction (x 1)	No observed dysfunctions

Figure 21 – PDT-Com scoring criteria for the forward lunge showing rear and sagittal view examples

3.2.3 Scoring Criteria for the Single-Leg Squat

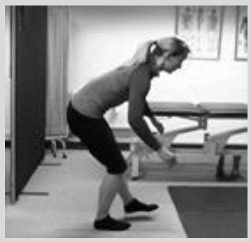
PDT Scoring Criteria - SLSQ			
Frontal View			
Sagittal View			
Score	**1**	**2**	**3**
Criteria	• Ankle Pronation • Knee valgus • Loss of balance • Poor sagittal trunk alignment • Knee flexion <90 degrees • Poor frontal plane trunk alignment	• Ankle pronation • Knee valgus • Loss of balance + Any other observed dysfunctions	• Ankle pronation • Knee valgus + Any other observed dysfunctions
Frontal View			
Sagittal View			
Score	**4**	**5**	**6**
Criteria	• Ankle pronation OR • Knee valgus + Any other observed dysfunctions	• Any observed dysfunction (x 1)	No observed dysfunctions

Figure 22 - PDT-Com scoring criteria for the SLSQ showing rear and sagittal view examples

3.3 MUSCLE FLEXIBILITY

Flexibility is one of the main performance-related variables of physical function and fitness (204). It is defined as the maximum physiological passive range of motion of a given joint movement (204). Flexibility testing can be very informative and should form part of an assessment of physical function. Objective measures of hamstring and quadriceps muscle length are needed to quantify baseline limitations and to measure the effectiveness of a corrective intervention.

3.3.1 Flexibility Measurement Procedures

Hamstrings

The hamstring muscle group is composed of the semi-tendinous, semi-membranous and biceps femoris muscles, and forms a large muscular mass that is directly involved in the movements of the hip and knee joints (84). The hamstrings perform an important role in the anteroposterior movement of the pelvis and indirectly affect curvature of the lumbar spine (205). Therefore, altered flexibility of the hamstrings may produce significant postural deviations and affect the functionality of the hip joint and lumbar spine (205). Specifically, in older adults, restriction in this muscle group can lead to reductions in stride length and walking speed, which in turn can disturb dynamic balance capabilities (206).

Clinically, hamstring muscle length is measured indirectly by goniometric measurement of unilateral hip flexion in a supine position (207). While the sit-and-reach tests are probably the most common measurement tools used for evaluating hamstring and lower back flexibility (206, 208, 209), they are ruled out as an objective measure of baseline limitations for this study on account of the problems they can pose for some older adults. It not only fails to isolate the hamstrings, but it is also inappropriate in the cases of older adults unable to get down and up from the floor, or who are perhaps lacking the abdominal strength required to hold a sitting position on the floor (206). For this reason, the more widely accepted and reliable passive straight leg raise was selected as a criterion measure of hamstring flexibility (206).

Length of the hamstrings was determined in the supine position using the passive single leg raise. The leg not being measured remains on the table with the knee flexed at 90 degrees over the end of the table (Figure 23). The leg was passively lifted to the end range of motion (firm end feel) or when movement in the lumbar curve was noted. The angle of hip flexion was measured using a universal perspex goniometer (Physiomed, Manchester, UK), which was aligned on the axis of the hip joint (Figure 23).

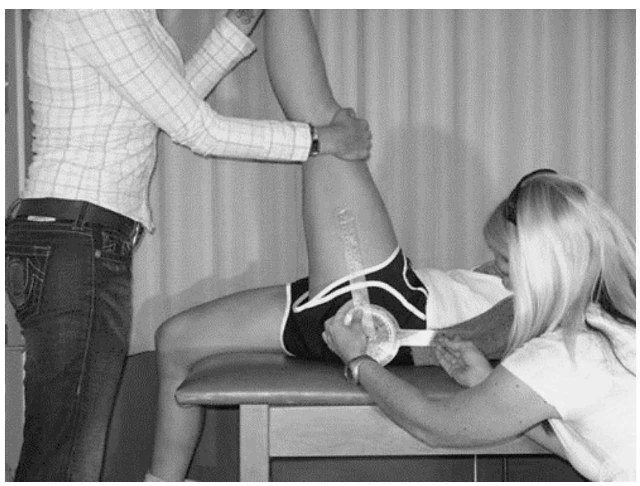


Figure 23 – Hamstring test position showing a PDT-Com score of 5 (80-90 degrees) as measured using a universal goniometer

Quadriceps

Length of the quadriceps was determined by measuring the knee angle during passive knee flexion, with the subject in the prone position (210, 211). The leg not being measured remains flat on the table. The lower-limb was passively lifted to end range of motion (firm end feel) or when the upward movement of the pelvis was noted. The angle of knee flexion was measured using a universal goniometer, which was aligned on the axis of the knee joint (Figure 24).

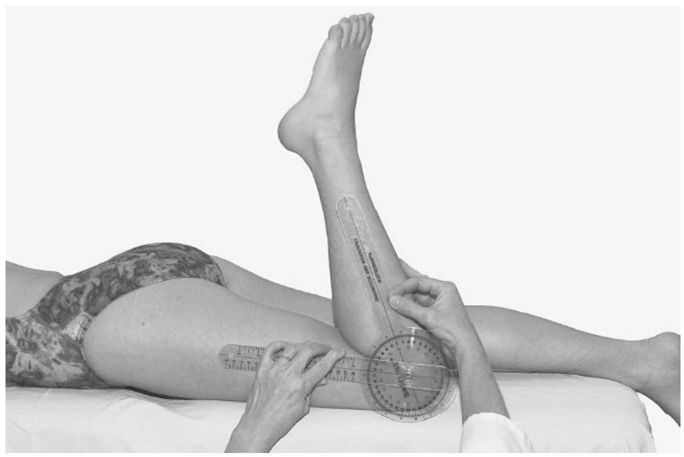


Figure 24 – Quadriceps test position showing a PDT-Com score 3 (70-79^o) as measured using a universal goniometer

Scoring Criteria

The scoring criteria for the hamstring and quadriceps muscle groups are presented in Table 6.

Table 6 – Scoring criteria for the hamstring muscle group

	PDT-Com Score					
Muscle Group	**1**	**2**	**3**	**4**	**5**	**6**
Hamstring	<40^o	40-49^o	50-59^o	60-69^o	70-79^o	80-90^o
Quadriceps	≥90^o	80-89^o	70-79^o	60-69^o	50-59^o	<40

3.4 MUSCLE STRENGTH MEASUREMENT: HAND-HELD DYNAMOMETRY

The measurement protocol used to measure and record lower-extremity muscle strength using HHD will have an effect on the results obtained. It was therefore vital to develop a rigorous measurement protocol to test, and if acceptable, use to develop a scoring system based on reference values for the PDT-Com in Chapter 8.

The HHD protocol was developed through clinical expertise and consultations with both physiotherapy and strength and conditioning colleagues. There is currently a lack of consensus on the most appropriate testing positions for HHD use, with one recent systematic review in particular responding to the wide variety of methods used for lower limb assessment in previous research (102). Based on published HHD research and pilot developmental work and assessments undertaken in different convenience samples, the protocol described in Appendix H was implemented. These testing positions have been found to demonstrate reliability for the measurement of isometric strength in previous studies investigating muscle actions of the hip (212), knee (213), and ankle (213).

3.5 APPLICATION OF THE PDT-COM

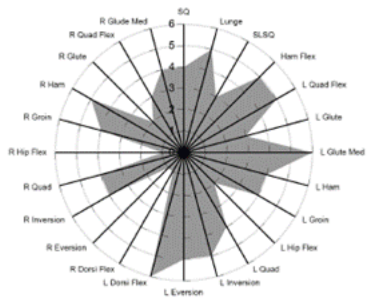
The PDT-Com is a comprehensive assessment tool that provides detailed information on lower-extremity muscle strength, imbalances and movement dysfunction that provide insight into an older persons impairments. In a clinical setting, time to complete the PDT-Com assessment procedure is approximately 20 to 30 minutes. Where time constraints may be an issue (i.e. busy clinical settings) a shorter version of the PDT-Com may be more appropriate. A bespoke web-based computer software programme using other data from the PDT-Com assessment has been developed. This gives the health care professional the ability to assess an individual's performance in relation to a reference or normative database built up from other populations. The software programme provides the following:

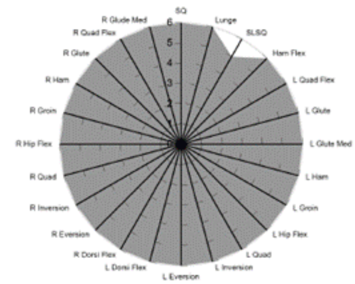
- A radar graph indicating an individual's total and composite scores
- A profile of each individual's score to allow quick and easy identification of physical performance strengths and deficits
- A written report that explains the results and makes recommendations for corrective exercise intervention

3.5.1 Assessment Results Output

Figure 29 illustrates a typical PDT-Com results output graph generated using the web-based software programme. This example is provided for a 65-year-old woman. The output is a graphical representation of the raw data collected during the assessment process, and collates scores for the domains of muscle force, muscle flexibility and movement competency. The composite scoring table below each output provides data that further highlights areas requiring attention. Reassessments can be applied at different time intervals to monitor each person's progress and to inform any adaptations to any recommended exercise intervention.

Colored areas in the output graph (Figure 25) inform the health professional whether there are deficits between sides (shape either jagged or smooth), while at the same time informing of the magnitude of these deficits (size i.e. towards the middle or outer edge). Individuals can be compared to their own baseline measures as well as external reference data with age-matched groups stratified by gender, based on data from more athletic populations.





PDT Composite Scores

Hip	Raw	%
Left	23	63.9
Right	20	55.6
Flexion	11	45.8
Extension	14	58.3
Total	43	59.7
Lower-limb		
Left	16	66.7
Right	6	25.0
Total	22	45.8

	Raw	%
Total Left	39	65.0
Total Right	26	43.3
Movement	12	66.7
Flexibility	13	72.2
Total composite	90	57.7

PDT Composite Scores

Hip	Raw	%
Left	36	100.0
Right	36	100.0
Flexion	24	100.0
Extension	24	100.0
Total	72	100.0
Lower-limb		
Left	18	75.0
Right	18	75.0
Total	36	75.0

	Raw	%
Total Left	54	90.0
Total Right	54	90.0
Movement	17	94.4
Flexibility	18	100.0
Total composite	143	91.7

Figure 25 - A typical PDT-Com results output graph showing pre/post three-month intervention scores

3.5.2 Interpretation of findings from PDT-Com Testing

Figure 26 highlights deficient areas which can be used to inform exercise prescription. For example, white areas (highlighted) clearly denote a muscle strength deficit in the right side lower-limb, right side hip extension and bilateral hip flexion which could potentially be improved using specific, targeted corrective exercises. The test findings suggest that lower scores ranging from 1 – 3 denote poor to average performance and efforts need to be made to improve performance using suitable corrective exercises or coaching. Scores ranging from 4 – 6 are indicative of above average to good performance which do not require immediate attention.

However, total PDT-Com scores can be misleading, and care must be taken when interpreting these. For example, a high total PDT-Com score can mask deficits in the composite scores. Although a relationship exists between sub-scores and the total test score, consideration should be given to all components of the test. .

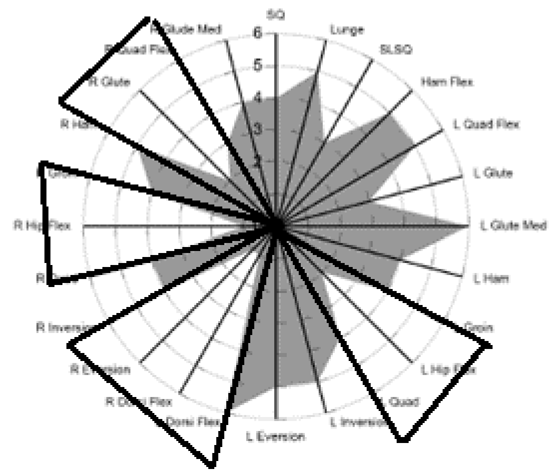


Figure 26 - PDT-Com output graph highlighting several potentially modifiable deficits in physical function

3.6 PDT-COM LIMITATIONS

The PDT-Com was originally developed (outside of this doctoral thesis) to specifically identify and quantify an individual's deficits in muscle strength, movement competency, balance and mobility. The author acknowledges, however, that there are other physiological risk factors that may contribute to movement competency not included in the PDT-Com assessment battery, such as psychological factors (e.g. depression, dementia, cognitive ability etc.), polypharmacy and aspects of concurrent physical disease (Parkinson's, stroke, metabolic syndrome, vestibular disease etc.) . As a result, the PDT-Com needs to be viewed as a complementary assessment to the current approach of assessment of falls risk.

3.7 CHAPTER SUMMARY

This chapter has outlined and described the PDT-Com scoring criteria, including application of the PDT-Com and the format of the computer-generated output. The PDT-Com test can be used alongside other assessment batteries to complement the assessment of community-dwelling older adults who are at risk of falling. A major strength of the PDT-Com test is that it provides valuable quantitative information for the reasons underpinning poor physical performance by highlighting specific areas that require modification. Thus, if these results are correctly interpreted, these findings may assist the health professional in the prescription of an individualised, targeted exercise intervention.

4 VALIDITY OF THE PDT-COM TEST

4.1 INTRODUCTION

In the previous Chapters, the concepts and original development of an objective assessment for use on an older adult population has been introduced. It is important that assessment tools and tests actually capture what they are designed to measure. This Chapter presents an overview of the definition and concept of 'validity' and outlines literature to support the validation of the newly developed PDT-Com assessment protocol.

4.2 DEFINITION OF VALIDITY

Validity is an attribute that should be strived for in any form of clinical measurement. The validity of a measurement indicates the degree to which the scores from the test, or instrument, measure what it is supposed to measure (214). Therefore, validity refers to the soundness of the interpretation of scores from a test, the most important consideration in measurement (215). There are different purposes for using certain measures. Consequently, several aspects of validity exist which are logical, content, construct and criterion-referenced validity (215). Construct validity and criterion-referenced validity relate to whether a test actually measures what it is intended to measure, whilst content validity and concurrent validity relate to whether the test can be used for the purpose it is designed (215).

Criterion-referenced validity

Criterion-referenced validity is concerned with validating a measurement against some criterion or 'gold' standard (216). The original term of 'gold standard' refers to a commitment by participating countries to fix the prices of their domestic currencies in terms of a specified amount of gold (216). The concept is that gold remains valid and stable over time, and as the value of gold is seldom stable nowadays, it is no longer used by countries as a basis for their monetary system (216). That said, the concept of a 'gold standard' for comparison has been adopted in many areas of measurement. Specifically, a gold or criterion standard is a method/tool or test that hypothetically has a sensitivity and specificity of 100% (no false positives and no false negatives). In practice, there are no gold or criterion standards. Therefore, there is the potential for a gold standard to change if a more specific and/or sensitive method is found (216).

Concurrent validity is a type of validity that involves correlating an instrument with a criterion that is administered at the same time (215). For example, in the context of lower-extremity muscle strength, this could refer to when measurements are first obtained using an HHD followed by a fixed isokinetic dynamometer. ***Predictive validity*** is when a new measuring method is applied at baseline and compared to outcome measures at a later date. Of specific interest is how closely the measurements obtained by HHD relate to those obtained using fixed isokinetic dynamometers because the latter are not reliant on the strength, ability and positioning of the rater. ***Construct Validity*** is the ability of a test to represent the underlying theoretical basis upon which outcomes of the test are interpreted (217). ***Content Validity*** measures whether a test contains all the necessary features that might be expected from a test (ADD ref), thus in the context of lower limb assessment, we would expect a test designed to assess efficiency of movement to include measures of the lower limb.

4.3 VALIDITY OF THE PDT-COM TEST CONTENTS

4.3.1 Hand-held dynamometry

As described, validity is how well a test measures what it is intended to measure in a specific population (214). The validity of hand-held dynamometry for the measurement of isometric lower-limb muscle strength in community-dwelling older adults is well documented in the literature (218-222). Arnold *et al* (218) demonstrated moderate to high correlation values when comparing HHD results against a gold standard isokinetic dynamometer ($r = 0.57$-0.86; $p < 0.05$) in a small sample of older adults ($n = 18$, Age 65 to 92 years). Similarly, Bohannon (223) examined the validity of knee extension force in older women ($n = 55$, mean age = 75, standard deviation (SD) 8.6 years). He concluded that these measures proved to be valid and a legitimate procedure in this population.

4.3.2 Validity of movement Screening Tests

Health professionals need to determine which movement tests are valid for use during evaluation of older adults for the identification of impairments. For instance, a relationship of a functional performance test to range of movement or lower-extremity muscle strength values may offer evidence of validity when compared to a functional movement test.

Another type of validity referred to as 'criterion-referenced' describes the extent to which a test is correlated with other gold-standard tests (217). As previously mentioned, the gold standard for assessing kinematics during dynamic tasks is by undertaking detailed three-dimensional (3D) motion analysis. These biomechanical tests are usually characterised by high criterion-referenced validity (197, 198). However, laboratory tests are generally expensive, complex, and time-consuming which is why they are considered not suitable for routine clinical practice.

Therefore, functional performance tests like the PDT, which require the integration of multiple body regions and systems to execute movement patterns, may have an advantage over more traditional clinical measures. Components of muscular strength, coordination, balance, and motor control of multiple regions can be assessed simultaneously by observing the movement patterns in which a person normally functions (111). The documentation and standardisation of whole-body functional movement competency protocols is relatively unexplored. However, researchers have examined validity of the squat, lunge and SLSQ movements in the context of movement competency.

The squat

The squat has long been one of the most prevalent exercises assessed in the strength & conditioning and rehabilitation environments (147, 149, 154, 224, 225). The popularity of this movement reflects the many benefits associated with squat performance which are not only limited to the athletic population. Given that most activities of daily living require the simultaneous coordinated interaction of many muscle groups, the squat is considered one of the best exercises for improving lower-extremity function because of its ability to recruit multiple muscle groups in a single movement (147). The squat has been used to identify movement impairments and underlying causal factors such as tibialis posterior dysfunction, knee pain, sacroiliac joint dysfunction and a higher risk of anterior cruciate ligament injury (84).

The forward lunge

Validity of the forward lunge has been established by several researchers (138, 367, 368). The lunge pattern is one of the seven fundamental movement patterns performed in activities of daily living, as described by Cook (111). It can simply be described as an elongated step forwards, flexing the lead hip and knee while dorsiflexing the lead ankle joint and lowering towards the floor (171, 226). Several different lunge patterns have been used to assess balance, strength and flexibility (145, 172, 177, 226, 227). Like other closed chain movements, the forward lunge offers the advantages of promoting similar muscle activation patterns to those of daily activities (171, 227), and replicating movements seen in the gait cycle (227). Furthermore, the lunge has been described as a safe exercise for use by some fitter older adults (171), and a recommended exercise intervention to reduce falls in this population (228).

The single leg squat (SLSQ)

Acceptable levels of validity for the SLSQ and other unilateral movements have been established by several researchers (377-379). The SLSQ is a simple test of physical function and provides the health professional with useful information with regards to biomechanical faults during transitional movements. The SLSQ is promising as a functional test since it involves both daily activity and athletic tasks (229), and its validity and reliability has been examined by numerous researchers through different methods and assessment tools (187, 188, 229). A modicum of descriptive reports on the kinematics of the SLSQ have emerged in recent years (180, 192, 199, 230-234). For example, evidence indicates that an excessive valgus angle at the knee during functional tasks is a risk factor for non-contact anterior cruciate ligament injury (149, 192, 235), and for overuse injuries such as patellofemoral pain syndrome (195). One review in particular concluded that mounting evidence of faulty lower-extremity movement patterns contributed to knee injuries across all age groups (236).

4.4 SUMMARY OF VALIDITY

The PDT-Com may provide allied health professionals with a better understanding of an older adult's movement ability and their awareness of what constitutes good movement competency.

Important information may be gained simply by observing an older adult's kinaesthetic awareness during the performance of the PDT-com movement tasks. Therefore, an older adult's movement competency may provide insight into additional risk factors for falling. This information may prove valuable prior to exercise prescription for the purpose of fall risk reduction. Enhancing the communication between health professionals to ensure that exercise programmes accommodate older adult's movement ability, and that training adaptation contributes more to an increase in physical performance. The PDT-Com developed and validated in this study may fulfil these objectives and may be effective at identifying a broad range of movement-related risk factors that would otherwise go unnoticed in traditional assessment protocols. However, many of these assumptions require further investigation. The next phase of this thesis will cover evidence from the literature, before presentation of findings from further investigation of the validity and reliability of the PDT-Com assessment test.

5 LITERATURE REVIEW: FALLS IN OLDER ADULTS

5.1 INTRODUCTION

This Chapter introduces the problem of falling in the older adult population and discusses some of the well documented fall risk factors, including an overview of the content of national fall prevention guidelines. This sets the context of why falling is such a public health burden and outlines the need for prevention and treatment strategies.

5.2 EPIDEMIOLOGY OF FALLING IN OLDER ADULTS

The number of fallers in the older adult population is a major global public health problem (2, 20, 237, 238). Low-level falls are common amongst all age groups yet falls in the older adult population are associated with considerably higher morbidity and mortality rates (2, 3, 239-241). Consequently, a greater burden is placed on healthcare institutions and their workforce, resulting in rising costs in line with the ageing population growth (239).

5.2.1 A Global Problem

As the proportion of people aged sixty and over in the population continues to grow, the number of falls and subsequent injuries has increased (242). Ageing is associated with a number of physiologic and functional declines that can contribute to an increased risk of falling (243). Data from the World Health Organisation (WHO) reports dramatic increases in global life expectancy since 2000, increasing by five years between 2000 and 2015, the fastest increase since 1960 (238). Life expectancy at age 60 has also been increasing globally – from 18.7 years in 2000 to

20.4 years in 2015, and specifically to 22 years in the WHO European region (238). The number of people worldwide over 60 years is expected to grow from 688 million in 2006 to almost 2 billion by 2050 (2). A recent review (237) reported life expectancy in the UK had risen from 76 years in 1990 to 80 years in 2009.

The associated stress on healthcare systems in Westernised countries is striking; falls were recently reported as the leading cause of hospitalisation in the US and Australia (244, 245). In the US in 2014, there were over 2.5 million older adults treated in emergency departments for a non-fatal fall, accounting for 65% of all injuries (244). Of these, nearly 1 million were hospitalised at a direct annual cost of $31 billion (244, 246). In Australia between 1999 and 2011, the patient days for hospital care directly attributable to fall-related injuries more than doubled from 0.7 million in 1999 to 1.7 million patient days in 2011 (245).

Older adults are more prone to injury than their younger counterparts, and a fall in the older adult will bring about far greater consequences. For example, in Australia the largest proportion of fall injury cases for people aged over 65 in 2010-11 resulted in injuries to the hip and thigh, in particular fractures to the neck of the femur (hip fracture) (74%) (245).

5.2.2 Falls in the United Kingdom

In the UK , it is estimated that 30% of community-dwelling people over the age of 65 years, and 50% over 80 years, fall at least once each year (3). Falls have a devastating effect on older adults living in the community in terms of morbidity, mortality, and loss of independence (2). It is well documented that the risk of falling increases with age, and that falls resulting in injury are an expensive contributor of accident and emergency (A&E) treatment and hospital admissions (3). Although most falls result in no or minor injury, approximately 5% of older adults in a community-dwelling setting who fall in a given year experience a fracture or require hospitalisation (247).

The Burden on Healthcare

Recent UK guidelines have reported that more than 400,000 older adults attend accident and emergency departments following an fall, while up to 14,000 people die annually in the UK as a result of a hip fracture (3). In the UK during 1999, there were 647,721 A&E attendances and 204,424 admissions to hospital for fall-related injuries in people aged 60 years and over (239). Of these attendances, of those aged 60-64 years just over a third (37%) required hospital admission and further treatment. For patients aged >70 years, this percentage increased to almost two thirds (63%) who required further examination or treatment. The rate of A&E attendances per 10,000 population for unintentional falls in the >75 age group was almost three times that of those aged 70-74, and more than three times that of the lower age groups (60-64 and 65-69) (Table 8).

Most of the A&E attendances across all age groups were due to a ‘fall from same level (slip, trip or stumble)’. However, the second most common fall category (fall on or from stairs/steps) becomes the least common with increasing age. Hospitalisation rates were highest in the >75 age group. Patients in this age group proved over four times more likely to be hospitalised for unspecified falls than those aged 70-74 years, almost seven times more likely than those aged 65-69 years and almost eleven times more likely than those aged 60-64 years. The main fall category for hospital admissions across all age groups was ‘unspecified falls’. Across all age groups those attending A&E for an accidental fall were more likely to be admitted for an ‘unspecified fall’, and least likely to be admitted if they sustained a ‘fall on or from stairs/steps’.

Table 7 - Accident & Emergency department attendance & hospitalisation rates in 1999. From Scuffham et al (2003) (3).

Fall category	**Fall on same level (slip/ trip/stumble)**	**Fall on or from stairs/steps**	**Fall from one level to another**	**Unspecified fall**	**Total**
A&E attendance rate per 10,000 population					
60-64	113.4	76.7	36.7	46.7	273.5
65-69	141.4	77.5	18.9	49.5	287.3
70-74	159.6	65.7	37.9	104.7	367.9
>75	397	110.8	117.1	320.4	945.3
Hospital admission rate per 10,000 population					
60-64	11.7	5	2.1	15.8	34.6
65-69	17.6	6.2	3.4	24.9	52.1
70-74	27.3	8.8	6.3	49.5	91.9
>75	89.8	18.5	29.8	230.5	368.6
Percentage of A&E accidental fall attendees admitted to hospital					
60-64	10.3	6.5	5.7	33.8	56.3
65-69	12.4	8.0	17.8	50.2	88.4
70-74	17.1	13.4	16.7	47.3	94.5
>75	22.6	16.7	25.4	71.9	136.6

KEY: A&E = Accident & Emergency

Cost Implications

Because of the rising costs to the patient and society in the United Kingdom (UK), much work has been done in preventing falling among all populations across the spectrum of healthcare. Numerous studies have been conducted examining the annual incidence of falls in the UK. Inconsistencies in the research methodologies, including the use of different fall definitions, explain some of the disparity in the results of these studies (73).

The cost of unintentional falls in the UK per 10,000 population is given in Table 8. In 2003, the total economic cost of falls in the UK for people aged over 60 years was estimated to be £981 million (239). Falls in those aged over 75 years accounted for 78% of unintentional falls and 66% of the total cost (£647 million) (239). Due to the date of publication, it is likely that the financial picture is now worse than these older data suggest.

Table 8 - Cost of Accidental Falls per 10,000 population. From Scuffham *et al* (2003) (239)

	Fall on same level from slip, trip or stumble	**Fall on or from stairs or steps**	**Falls from one level to another**	**Unspecified fall**	**Total**
	(£,000)	(£,000)	(£,000)	(£,000)	(£,000)
60-64	65.4	30.9	80.9	101.9	279.2
65-69	173.1	74.5	20.8	319.0	587.4
70-74	163.8	63.3	23.5	180.9	431.5
>75	458.5	60.5	138.1	838.9	1,496.1

*Incidence data from 1999 and values expressed as UK pounds in year 2000

As the older population increases, it is likely that the costs attributed to falls will increase the stress on the NHS and the social services (239). However, these figures may not represent the total true cost of falling as the authors reported that few cost data came from community services, GP consultation costs for less serious falls, and the expenses incurred by direct admissions to care services.

5.3 RISK FACTORS FOR FALLING

The risk of falling increases in older adults with chronic and developmental conditions and diseases. (33, 248, 249). However, this population of older adults diagnosed with co-morbidities such as Parkinson's Disease, dementia, chronic pulmonary obstructive disease and hypertension are not the subject of this thesis.

Most falls result from the interaction of multiple factors, and the more risk factors an individual has the greater the chances of falling (2). Risk factors have been generally categorised as either internal or external to the environment (250). The following sections present potential risk factors in these categories. Several of these factors can be used by healthcare professionals to devise suitable individualised and evidence-based intervention programmes.

5.3.1 Intrinsic (Physiological) Risk Factors

Intrinsic fall risk factors are presented in Table 9. Some fall risk factors are irreversible while others are potentially modifiable with appropriate interventions (4). Intrinsic, or physiological, risk factors for falls have been found in controlled studies, which allow the identification of those at risk and suggest potential preventive interventions (251). These potentially modifiable factors are many and include impairments in gait function, balance ability, deficits and asymmetries in lower-extremity muscular strength, joint range of movement (ROM) and biomechanical alignment (12, 13, 37, 42, 50, 52, 243). Heightened awareness and understanding of these declines associated with falling is therefore warranted. In the community setting, where many but not all people have a high level of functional ability, factors associated with the transition in status from non-faller to faller need to be better understood (43). The main risk factor for falling identified in prospective cohort studies is a recent fall history. However, in the absence of a previous fall, other factors need to be evaluated that are associated with the transition from non-faller to faller (43).

Intrinsic factors can be further categorised into ‘modifiable’ and ‘unmodifiable’. Age, gender, ethnicity and previous falls all constitute intrinsic factors that cannot be modified. Several studies have shown that increasing age is associated with increased risk of falling (18, 44, 71). Gender is associated with an increased risk, with women being more likely that men to sustain a fracture when they fall (252). It has been reported that Afro-Caribbean and South Asian people fall less frequently than their Caucasian counterparts although this may be due to measurement or respondent bias (44, 253). Currently there are no data for Continental Europeans. However, factors such as physical activity, balance ability and muscle strength, including the use of walking aids and nutritional deficiencies, can be modified through targeted intervention.

Table 9 - Internal & External Fall Risk Factors. Adapted from Renfro *et al* (254)

Risk Factor Category	**Modifiable**	**Unmodifiable**
Intrinsic/Physiological	Impairments in Gait Function	Back Pain
	Physical Inactivity	Gender
	Lower-extremity Muscle Weakness	Ethnicity
	Poor Balance Ability	History of Falls
	Poor Vision Care/Treatment	Visual Impairment
	Nutritional Deficits (vitamin D)	Chronic Disease
	Fear of Falling	Cognitive Impairment
	Back Pain	
External	Trip Hazards	
	Improper Footwear/Clothing	
	Stairs	
	Wet Floors	
	Uneven Surfaces	
	Furniture	
	Low Chairs/Toilets/Sofas	
	Poor Lighting	

5.3.2 External or Environmental Risk Factors

Some examples of common external risk factors are presented in Table 9; these are environmental factors associated with increased risk of falling. Although these risk factors are potentially modifiable, these are not the focus of this thesis.

5.3.3 Muscle Weakness

Muscle strength and power is required for the successful performance of activities of daily living, and muscle weakness is linked to an increased risk of falls in older adults (13, 14, 22, 25, 46, 47, 50, 52, 54, 159, 178, 208, 219, 228, 230, 255-288). It has long been established that engaging in some form of muscle strengthening activity, such as resistance training, has an impact on a range of health and morbidity related risk factors (264, 289-291), including the prevention of falls in older adults (54, 55, 57, 60, 62, 110, 250, 292-296).

In direct response, participation in strengthening activities is recommended for people of all ages (9, 297-299), but these activities may not produce the desired outcomes. For example, the National Health Service (NHS) currently recommends muscle strengthening activities such as gardening and yoga (300). However, these activities may not produce enough external force resistance to elicit adaptations in muscle strength. The lack of emphasis on resistance training within these NHS guidelines may be due to this misunderstanding of what constitutes resistance training. As a result, there is seemingly a reluctance to support an approach emphasising muscle strengthening through resistance training. Indeed, the most recent physical activity report (297) informing the current UK guidelines states *'the health benefits of strength training and flexibility should be positioned as secondary and less important than the primary message to adults of undertaking at least 150 min of aerobic activity per week.'* With policy makers claiming that resistance training has little importance, it is unsurprising that participation in this training modality has received little emphasis.

5.3.4 Physical Activity

Regular physical activity is one of the most important things a person can do to stay healthy. Physical activity can reduce the risk of developing certain diseases and can assist in the management of several chronic health conditions, such as arthritis and respiratory conditions (297). Much research shows poor performance in fitness related measures, across the lifespan, and these may be some of the strongest risk factors for quality of life, function, and increased risk of a range of morbidities, as well as increased all-cause mortality (301). Recent studies support similar correlational relationships between health, longevity, and cardiorespiratory fitness (299, 302, 303), in addition to other characteristics which are modifiable through physical activity and exercise, such as muscle mass (304, 305), and strength (25, 208, 273, 306). Not only will physical activity increase one’s chances of living longer, activity can also help control weight, reduce risks for cardiovascular disease, type 2 diabetes, metabolic syndrome, and some cancers. Physical activity strengthens bones and muscles, improves mental health and mood, and improves the ability to undertake daily activities and also help prevent falls among older adults (297, 298).

Paradoxically, it has be shown that increased levels of physical and recreational activity amongst sedentary older adults brings with it a slight increased risk of falling and musculoskeletal (MSK) injuries (6, 9, 17). This is because of increased activity and exposure to risk amongst adults who may be unused to physical activity and exercise. Thus, identification of known risk factors has increased in the field of sports medicine for active older adult populations.

Given that certain physical activities have been linked to an increased risk of falling (12, 24, 42, 43, 71, 307-309), it would seem prudent that an appropriate assessment tool had the ability to identify both the limitations and the underlying reasons for them. For example, Muir *et al* (42) found basic activities such as walking and stair climbing were being performed at the time of a fall in high-functioning community-dwelling older adults. Thus, subjects demonstrating poor physical ability below certain established thresholds would then be identified as having an increased risk of falling. The logical conclusion would be that on re-assessment subjects presenting with improvements in physical ability would, because of those improvements, decrease their risk of falling.

5.4 FALL PREVENTION GUIDELINES

The way forward, as proposed by the WHO Global Report on Fall Prevention in Older Adults (2), is to provide an action plan based on their 'Three Pillars' of falls prevention. These pillars are:

- building awareness of the importance of falls prevention;
- improving the assessment of individual factors that increase the likelihood of falls;
- facilitating the design and implementation of appropriate, evidence-based interventions that will significantly reduce the number of falls among older adults.

Similar proposals and recommendations have been communicated by several other international organisations and institutions, such as in a statement by the United States Preventative Services Task Force (USPSTF) (310). They concluded with moderate certainty that an exercise or physical therapy (physiotherapy) intervention has a moderate net benefit in preventing falls. The National Institute on Aging in the US recommends strength and balance exercises for the prevention of falls (311). Similarly, Exercise and Sports Science Australia, in a position paper on exercise and falls prevention in older people, state the importance of lower-extremity muscle strength, gait and balance training, all of which can be improved with appropriate exercise (56).

5.4.1 Policy in the United Kingdom

The UK National Falls Prevention Coordination Group (NFPCG) is made up of different organisations involved in the prevention of falls, in the care of falls-related injuries and the promotion of healthy ageing (312). The NFPCG outlines an approach needed to reduce the number of falls and their impact, by member organisations committing to working in collaboration with national and local partners, to promote healthy ageing for all through the collective and targeted use of resources, skills and knowledge in order to:

- reduce falls and fracture risk across the life course and patient pathway;
- improve treatment including secondary prevention for those older adults who have suffered injury following a fall.

A joint article by the American and British Geriatric Societies entitled Clinical Practice Guideline for the Prevention of Falls in Older Adults was published in May 2001 (5) and further updated to provide revised recommendations in 2011 (15). Evidence provided in the report was graded based on five levels of quality and magnitude of benefit for each intervention, with the authors assigned a quality rating of A, B, C, D or I to each recommendation (Table 10).

The updated recommendations stated that all multifactorial interventions for community-dwelling older adults should have an exercise component. Furthermore, the 2011 guidelines specified that exercise programmes should include balance, gait, and strength training, such as Tai Chi or physical therapy, in group programmes or as individual programmes at home. Once screening has identified older adults at risk of falling, they should be directed towards a multifactorial fall risk assessment (Figure 27).

Table 10 **–** Evidence rating system descriptions used to grade recommendations (15)

Rating	**Description**
A	a strong recommendation that physicians provide the intervention to eligible patients
B	a recommendation that clinicians provide this intervention to eligible patients
C	that no recommendation for or against the routine provision of the intervention can be made
D	that the panel recommends against routinely providing the intervention to asymptomatic patients
I	Insufficient evidence for or against an intervention

At this stage, a detailed assessment of gait, balance, mobility level and lower extremity joint function is recommended, as well as an assessment of lower-extremity muscle strength and functional ability during activities of daily living. Recommended interventions taken directly from these guidelines (15) include, but not limited to (grade of evidence given in parenthesis):

- Direct interventions customised to the identified risk factors, coupled with an appropriate exercise programme should follow the multifactorial fall risk assessment (A);
- The components most commonly included in efficacious interventions were exercise, particularly balance, strength, and gait training (Grade A);
- All older adults who are at risk of falling should be offered an exercise programme incorporating balance, gait, and strength training (Grade A);

- Exercise should be included as a component of multifactorial interventions for fall prevention in community-residing older adults (Grade A);
- Exercise may be performed in groups or as individual (home) exercises because both are effective in preventing falls (Grade B);
- Exercise programmes should consider the physical capabilities and health profile of the older adult (i.e., be customized) and be prescribed by qualified health professionals or fitness instructors (Insufficient evidence);
- exercise program should include regular review, progression, and adjustment of the exercise prescription as appropriate (Insufficient evidence);

The National Institute for Health and Care Excellence (NICE) clinical guideline CG161 was issued in June 2013 and updates and replaces the NICE guideline CG63 of March 2008 (3). The guideline covers assessment of fall risk and interventions to prevent falls in people aged 65 and over. It aims to reduce the risk and incidence of falls and the associated distress, pain, injury, loss of confidence, loss of independence and mortality. It goes on to state that *'older people who present for medical attention because of a fall, or report recurrent falls in the past year, or demonstrate abnormalities of gait and/or balance should be offered a multifactorial falls risk assessment*. *This assessment should be performed by a healthcare professional with appropriate skills and experience, normally in the setting of a specialist falls service. This assessment should be part of an individualised, multifactorial intervention.'*

The contents of the NICE guideline were reviewed in 2016 and a decision was made not to change the recommendations. The following key priorities are recommended for implementation:

- Older people in contact with healthcare professionals should be asked routinely whether they have fallen in the past year and asked about the frequency, context and characteristics of the fall/s.

The 2016 review process found several recently published studies relevant to the existing guidelines. One was highlighted which may have an impact on the recommendations relating to strength and balance training for falls prevention in community-dwelling older adults. Topic experts also referred to a Cochrane systematic review currently being updated and referred to the fact that being able to be more specific in terms of type and duration of exercise intervention would add value to the guideline. Considering this update, the reviewers decided it more appropriate to reassess the guideline when this was systematic review completed.

In addition to this, a joint consensus from the British and American Geriatric Societies produced a clinical algorithm (Figure 27) describing a step-by-step process of decision making and intervention that should occur in the management of healthy older adults who present with recurrent falls, gait and balance problems, or in the emergency department after a fall (313, 314). In the event of a gait, balance, mobility or strength problem being identified, an individually tailored exercise programme is recommended. However, the published guidelines by NICE recommends strength and balance training, which should be individually prescribed by an appropriately trained professional (241).

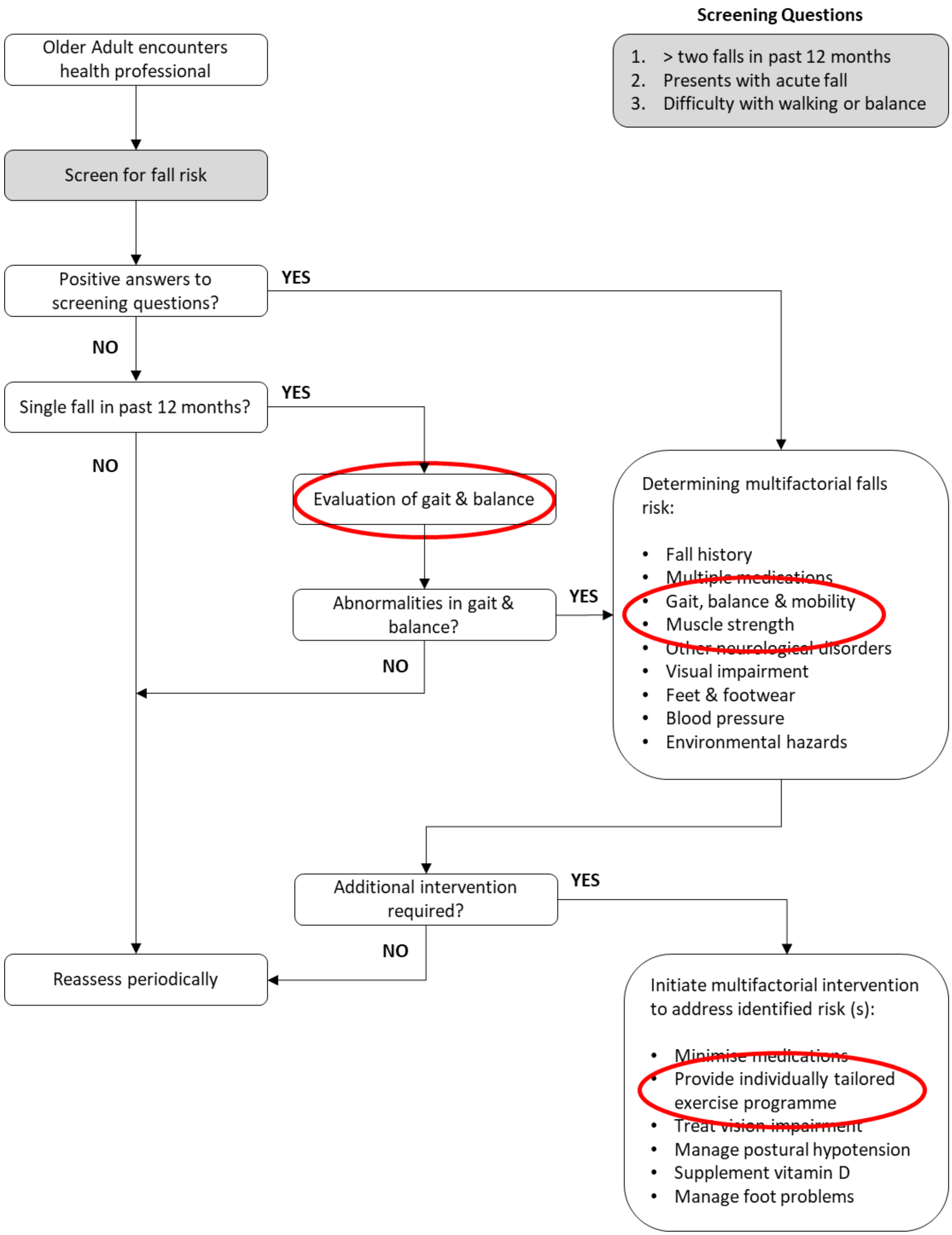


Figure 27 - Algorithm for assessing risk and preventing falls in older adults. Highlighted areas are relevant to this thesis. Adapted from American Geriatrics Society clinical practice guideline: prevention of falls in older adults (2010) (15).

Early clinical trials which examined the assessment of modifiable fall risk factors were promising and provided evidence to introduce mandatory falls services throughout the UK. These services, termed multifactorial falls prevention (MFFP) or multifactorial risk assessment and prevention (MFRA), served as secondary prevention for older adults who had already suffered a fall (240). However, some systematic reviews have shown mixed evidence of the effect of MFFP on outcomes of rate of falls and fall-related injuries (31, 64). There is now a move to study alternative strategies to reduce falling and fall-related injuries in older adults, such as the prevention of falls injury trial (PreFIT) (250).

Clearly, there is growing evidence supporting the effectiveness of exercise programmes to prevent falls, and widespread promotion of exercise as an effective intervention. Surprisingly, little is known about how best to implement an intervention when a patient has been identified as requiring exercise in a healthcare setting and defining the components of the programme may not be easy. The evidence underpinning the recommendations comes from high quality randomised controlled trials involving heterogeneous populations that participated in different combinations of balance, strength, endurance, or general exercise programmes in various settings under the supervision of diverse groups of experts (55, 64, 292, 315, 316). General guidance is provided, but details on how to construct or conduct an exercise programme is often missing, although these programmes have been proven to be effective. A joined-up approach may be warranted, as recommended by the USPSTF, to transform the evidence into a defined programme that spells out who should partake in what types of exercises, the setting and duration of the exercises, and the type of monitoring or supervision each participant will receive.

5.4.2 Screening for falls risk

The WHO define a screening test as 'the presumptive identification of unrecognised disease or defect by the application of examinations or other procedures which can be applied rapidly' (317). Put simply, screening is the process of identifying a subgroup of people who are at high probability of having asymptomatic disease or who have a risk factor(s) that puts them at high risk for developing a disease or becoming injured (318). Screening tests are routinely used in medicine to screen for, diagnose, grade and monitor the progression of disease. Screening tests may consist of machine imagery, clinical examinations and/or subjective assessments to determine whether someone has or is at risk of disease (319). These screening tests are simple and validated in a broad population to identify a dichotomous low or high risk. They are useful for identifying at-risk people to receive appropriate treatment.

Screening for falls and risk of falling is aimed at preventing or reducing fall risk and ensures that expensive multi-factorial interventions are targeted to those most likely to benefit. In the context of falls research, the consensus prevention of falls network group (ProFaNE) Taxonomy Domain 1 (A509) (75) describes a fall screening tool as 'a short test to determine an older person's risk of falling to determine eligibility for a fall risk reduction intervention programme'. It also goes on to state that 'It is not usually used to determine treatment received'.

Health services need reliable and effective screening tools to identify at-risk community-dwelling older adults so further assessments can be administered. Screening tools do not assist in the aetiology of falling, nor do they offer meaningful information to direct an intervention except to direct the patient to the relevant health professional. A positive answer to one or more screening questions or a physical test may highlight the need for further investigation using evidenced-based objective assessments.

5.4.3 Falls Assessments

After screening, further assessments are designed to highlight the causes and diagnose issues so that individualised interventions can be prescribed. These are undertaken after population screening and usually consist of gathering key information to collaboratively conceptualise the problem and develop a treatment plan. The data from assessments can be used for various purposes, including evaluating attainment and learning, monitoring progress, determining competency and diagnosing a problem. After an initial screening questionnaire or physical test to identify those at most risk, a battery of more detailed falls risk assessments are usually administered by a suitable health professional to refer patients to either 1) primary care, or geriatric management 2) other medical services, healthcare workers, or agencies as appropriate for selected problems or 3) emergency referrals to a general practitioner (320). Reductions in mortality and improved functional measures, including reductions in the admission to hospital and institutional care, have been reported in the UK and other settings (320-323), with the benefits of current multidimensional assessment protocols in geriatric care remaining controversial (320, 323, 324).

In the context of falls research, the ProFaNE Taxonomy Domain 3 (C200) (75) states that a fall risk assessment is 'a diagnostic process intended to determine an older person's risk of falling in order to plan coordinated treatment and long-term follow up'. Currently, assessments in fall prevention research only highlight specific intervention domains, such as strength/balance training and vision impairments, or dichotomously quantify functional status. However, these assessments can go one step further by identifying underlying reasons for muscle strength deficits, gait, balance and mobility problems which, in conjunction with other tests of function, can better individualise exercise programmes and track intervention effectiveness.

5.5 A NEW ASSESSMENT PARADIGM

Evidence based medicine, whose philosophical origins extend back to mid-19th century Paris and even earlier, has led to dramatic improvements in healthcare provision and therapies. However, this disease-centred model may not be the appropriate one to use in fall prevention research. For example, the gold standard of finding evidence for the most adequate treatments in health care is the randomised controlled trial (RCT), or rather, meta-analyses or review studies of only the highest quality RCTs. However, falling is not a disease per se but rather a combination of physiological, environmental, social and cognitive factors (14, 29, 42). If the goal of fall prevention research is that of strictly curative, it is likely to make the implied assumption that adequate physical function (strength, balance, flexibility, mobility etc.) and the absence of a fall are essentially synonymous. This assumption makes room for primary prevention, but it neglects to address the needs of community-dwelling older adults with chronic loss of physical function and other musculoskeletal conditions.

Interventions based on risk factors for falling include exercise programmes, education programmes, medication reviews, environmental modifications in homes or institutions, and nutritional or hormonal supplementation (325). With underlying factors for falling being multifactorial (medication, cognitive ability, physical impairment, fear of falling etc.), it may be beneficial to address physiological risk factors independently so that appropriate exercise interventions can be prescribed. Subjects who take psychotropic drugs or multiple medications in the absence of other risk factors are at higher risk of falling (3, 8, 34, 71, 326). Thus, it may be of benefit to categorise healthy community-dwelling adults as high risk of falling if, when assessed with an appropriate tool, they present with certain physical or psychological impairments. Clearly, the absence of fall history, multiple medications, disease or a cognitive impairment does not rule out physiological risk factors in otherwise healthy community-dwelling older adults.

The sustainability of falls prevention efforts is a priority in UK public health and geriatric medicine (327). As such, it is recommended that much time, effort and resources are required to develop, implement and evaluate the many fall prevention exercise interventions (327, 328). In response, Franklin and colleagues developed the Community Exercise Programme Assessment Matrix (referred to as the Matrix) for the assessment of physiological components within an exercise programme (327). The authors proposed that by evaluating existing programmes, modifications could be made to help reduce fall risk factors. Although this approach of fitting the exercise programme to the fallers seems intuitive, by fitting the fallers with specific exercises may produce superior intervention outcomes. For any exercise intervention to be successful it must be individually prescribed and tailored. This means identifying which physiological components need modifying for each person, and the specific exercises needed within these components.

One of the aims of a multifactorial fall risk assessment is to identify deficits in lower-extremity muscle strength. However, the conceptualisation of this measurement is poorly delineated in fall prevention research. Proxy measures of functional strength, such as a 30sCRT (Appendix H), quantify functional status but do not provide any information on which muscle groups are weak and require strengthening. One can argue that the 30sCRT is a useful measurement tool because it uses most lower-extremity muscle groups. However, the test score, which is the number of rises, does not inform the health professional which muscle groups are weak or underperforming. Community-dwelling older adults, by their very definition, are generally more active and experience mechanical loads much greater than their institutionalised counterparts. Each time a person crouches, kneels, squats, twists, steps, runs or jumps they are experiencing above normal mechanical loads. Therefore, it would seem sensible to assess for mechanical efficiency and deficiency alongside standard geriatric physical assessments, as a way of identifying specific deficits in this population.

5.5.1 'Disease' versus 'Physiological' Approach

Most assessment tools used in fall prevention research are 'disease-oriented' rather than 'physiological' when it comes to establishing a person's risk of falling. A 'disease' or 'population' approach is warranted for the initial screening to identify those older adults at risk of falling. If the aim is to discriminate between high and low risk of falling then, if available, tools with high sensitivity and high specificity should be chosen (329). Indeed, the American Geriatric/British Geriatric Society guideline suggests a simple screening algorithm be administered, in conjunction with a timed performance test. (15). This screening process is distinct from the more intensive assessment procedures that follow which identify potentially modifiable risk factors in multifactorial fall prevention programmes.

It must be remembered that the act of falling is an event not a disease, and that current assessment tools may not identify a person's modifiable risk factors or reasons for poor performance (330). The Timed-Up-&-Go test (331) and Berg Balance Scale (330) are two good examples, which have shown to be reliable and valid measures of fall risk in a variety of populations and settings (309, 332-347). As good as the psychometric properties of these tools are, their scores can only inform a health professional that impairment is present or absent. Therefore, the 'physiological' approach may offer a more detailed and meaningful measurement of physical ability independently of other fall risk factors, at the same time as providing information to individually prescribe an exercise intervention.

5.6 CONCEPT OF HUMAN MOVEMENT AND TASK SPECIFICITY

The science of human movement examines how the human body functions in an interrelated and interdependent scheme (96). The everyday functioning of the human body is a complex integrated and multidimensional system, not a series of isolated, independent parts (84, 96). Currently there are no fall risk assessments that measure movement competency. This area of human performance and its effects on modifiable physiological fall risk factors is unknown. The following section will review the important aspects of each component of the human movement system as it relates to physical function and movement.

5.6.1 The Human Movement System

In the last two decades, there has been much focus on the understanding of the processes used to maintain stability and control in functional human movement tasks by health professionals (90, 97, 348). Human movement science is the study of how the human movement system functions (Figure 28). This system consists of the muscular system (functional anatomy), the skeletal system (functional biomechanics) and the nervous system (motor behaviour). Biomechanics is the application of physics to examine how forces interact on the human movement system. Specifically, the motions that human movement produces (kinematics) and the forces (kinetics) that act on it (349, 350).

The optimum functioning of each component allows for neuromuscular efficiency during functional activities. Proper functioning of human movement depends on the structural and functional integrity of each these three systems. Length-tension relationships refer to the resting length of a muscle and the resulting force it can produce at its resting length (77, 84, 96). Each muscle has an optimum length at which it can produce optimum (not maximum) force. When a muscle is stimulated at less or greater lengths than this optimal length, force is also reduced (351).

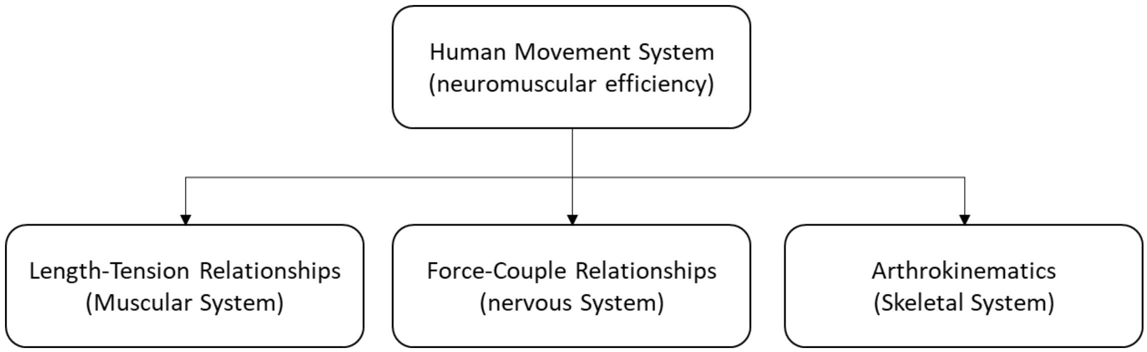


Figure 28. Components of the Human Movement System. Adapted from Clark (84)

Force-couple relationships refer to a group of muscles producing opposing contraction force onto their respective bones to produce movement at certain joints (84). Muscles working together in this way to produce movement are said to be working in a 'force-couple' relationship. However, unwanted movement can occur by a loss of force in one or several muscles in this relationship. Collectively, proper and efficient movement is a combination of optimum length-tension and force couple relationships, coupled with proper arthrokinematics (joint motion) (96).

5.6.2 Human Movement Impairments

During human movements gravity and momentum forces the body into the ground. The ground then exerts an opposite and equal force against us through the foot. This is known as a ground reaction force and places stress through the human movement system in a downwards and upwards direction (84, 350). As the speed of movement increases so does the ground reaction force (352). This can result in forces between one and 1.5 times one's body weight during walking (353), two to three times during running (353), and four to five times body weight when landing from a height of only 30cm (354).

An inability to demonstrate adequate movement competency against these forces (at varying thresholds of difficulty and/or external loads) may lead the person on a journey firstly towards below optimum physical performance (functional decline) and secondly to possible injury during normal daily activities. Furthermore, research demonstrates that humans employ muscle recruitment strategies for simple tasks that are normally reserved for higher-functioning activities (96). These altered movement patterns, and associated compensatory muscle recruitment, have been described in the literature as ‘faulty movements’ (355), ‘abnormal dominance of mobility synergists’ (356, 357), ‘muscle imbalance’ (97), ‘control impairments’, ‘substitution strategies’ (356, 357) and ‘movement impairments’ (96, 358). Due to the body always seeking to compensate for areas of pain, inhibition or weakness (90), poor movement competency, if it is objectively assessed, has the ability to expose areas that require attention (Figure 29).

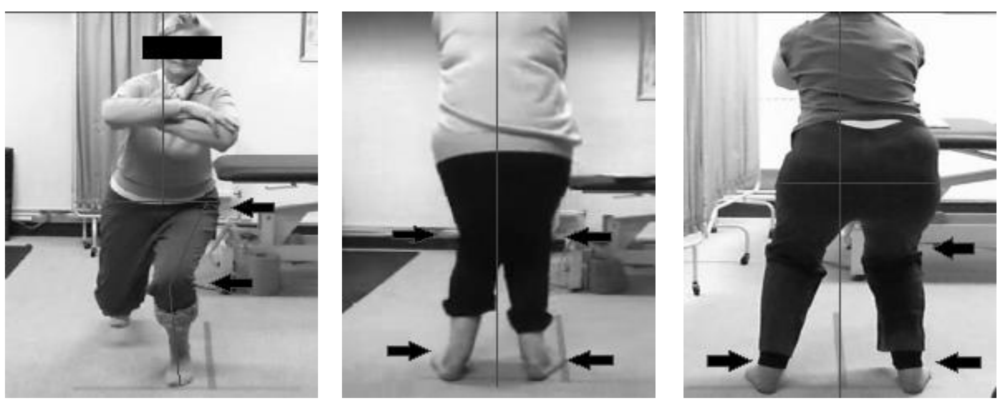


Figure 29 - Three older private rehabilitation clients (>60 years) presenting with poor movement competency

5.6.3 Movement Assessments

Movement is how all humans can perform physical activities, ranging from those necessary for sporting activities to activities of daily living (111, 150, 348). The ability to recognise optimal and efficient movement enables the health professional to identify suboptimal and/or abnormal movement patterns, which can indicate possible muscle asymmetries, balance and gait issues. All human movement, whether walking, jumping, running, stepping, throwing, kicking or catching, demands an expression of force production, force absorption (reduction) and force stabilisation (mechanical efficiency) (90, 348, 359). Optimally, these force 'events' should occur along the entire kinetic chain demanding multi-joint, multi-plane and multi-directional movement efficiency, and it is this that forms the foundations of human movement (359).

Movement assessments can be categorised into 'transitional' and 'dynamic' types. Transitional movements are typically those associated with activities where there is no change in the base of support, such as getting in and out of a chair and balancing. Dynamic movements are those associated with a change in the base of support, such as walking, running and jumping (84). As a result, the observation of these movements can potentially highlight dysfunctions in muscle length-tension and force-couple relationships, as well as restrictions in joint motion (arthrokinematics).

5.7 PHYSICAL ASSESSMENTS IN OTHER PARADIGMS

A battery of assessment and screening tools are available to rehabilitation and conditioning professionals for use with young, active and athletic populations. Typically, these evaluations are multifactorial in nature and cover multiple aspects of human movement and physical performance. The developers of these tools have consistently observed altered movement and muscle recruitment patterns in the presence of musculoskeletal pain. Because of these findings, several tools have been developed which have the potential to quantify movement ability. They are conceptualised by the fact that each movement tested forms the basis of more complex movements which all humans experience in every-day activities, whether sporting or non-sporting (111). The rationale for this movement-based approach is intuitively appealing because of the inclusion of fundamental movements that are characteristic of most activities of daily living.

There are several reliable and valid assessment tools that can be used to assess functional performance of older adults which will be subject to scrutiny throughout this thesis. For example, tools such as the 30sCRT (114), the Timed-Up-&-Go test (331) and the Berg Balance test (330) are frequently used in fall prevention research. However, these scores only provide discriminative values rather than information about the underlying factors that affect the scores. Therefore, the question remains, can assessment tools developed for use in the sports sciences and sports medicine disciplines be applied to different populations, thus older adults? The following section outlines and discusses several popular assessment tools used in these sports medicine paradigms.

5.7.1 Functional Movement Screen

One of the most popular and commercially successful tools in current use in the field of sports medicine is the Functional Movement Screen (FMS), developed and described by Grey Cook (157). The FMS is an inexpensive and easily administered assessment tool which has become increasingly popular for the evaluation of fundamental movement patterns critical to everyday human function. It consists of seven fundamental movement tests which have been chosen to categorise functional patterns. It is conceptualised by the fact that each test movement forms the basis of more complex movements which all humans experience in every-day activities, whether sporting or non-sporting.

Although few studies exist that have tested the FMS, preliminary data (360) shows the FMS to be a reliable and valid injury predictor in professional football in the United States. To further lend support for its use as a screening tool to predict injury, a study was conducted (202) which confirmed the inter-rater reliability of the FMS. Minick and colleagues (202) determined the inter-rater reliability of the FMS using a weighted kappa (K_w) statistic to measure the 'true' agreement, beyond that which is expected by chance. They compared results of four raters (two expert raters and two novice raters) using video recordings of 40 university students (23 women, 17 men, age circa 20.8yrs) performing the FMS. Results showed that neither pair of raters fell below a moderate level of agreement (K_w = 0.40 – 0.59), and when comparing scores between expert and novice raters, 14 of the 17 tests had excellent agreement (K_w = 0.83 – 1.0). Not only do these results suggest the FMS to be reliable between raters, but that reliable scoring can be obtained with novice scorers.

Despite its popularity, there is limited information available about the application of the FMS in older adults. Expanding on the research in younger more active populations, Perry and Koehle (361) reported normative FMS values and the effect of BMI in a wider age range of adults from young to old (n = 622, Ages from 21 to 82 years). They also described the association between physical activity levels and performance of the FMS, but reliability of the FMS as an assessment of functional ability in this age group was not specifically assessed. However, a recent study (362) concluded that the FMS is a reliable measure of physical function in older adults (n = 50, mean age = 58.9 SD ± 6.8) and that it may be used in this population in conjunction with existing assessments tools.

5.7.2 Athletic Ability Assessment

The Athletic Ability Assessment (AAA) is a relatively recent assessment tool, and was developed in 2014 as a direct result of the increasing popularity of FMS use in sporting populations (169). Several practitioners working in high performance sport revealed they were developing their own tests, suggesting that the FMS protocol may not be meeting their needs. The FMS was developed as a screening tool to establish whether it was safe for a person to exercise. Because of this, many questions have been raised over the relationship between FMS scores and improvements in sports performance (363-365). McKeown proposed the AAA be used to assess physical function because the movement requirements of an athlete are very different to that of activities of daily living. Reliability of the AAA in athletic populations has been established (169). The intra- and inter-rater reliability analysis of six raters testing 17 National level female football players was high (ICC = 0.97 and 0.96 respectively). Further studies are ongoing to examine the relationships between AAA scores and movement ability, injury risk and sports performance. Although specifically designed for athletic populations, the AAA is another example of the concept of assessing movement quality and the underlying reasons behind poor performance.

5.7.3 Movement Competency Screen

The Movement Competency Screen (MCS) was developed by the then New Zealand National Director of Strength & Conditioning, Mathew Kritz (366). This tool is in many respects similar to the AAA, in that the development was in direct response to the limitations of the popular use of the FMS in athletic populations. As a result, the AAA was designed to provide health and fitness professionals with a straightforward understanding of an individual's movement competency patterns as they relate to sports performance and activities of daily living. Since its development in 2012, the movement competency screen has been widely used in both physiotherapy and sports and conditioning professions within Australia, Malaysia, Philippines and North America, including High Performance Sport New Zealand, to guide the prescription of strength training and rehabilitation intervention programmes (366). The assessment tool has been shown to be reliable in a healthy, uninjured athletic population. Intra-rater reliability ranged from 0.73 to 1.00

with the overall average (Kappa = 0.93) indicating almost perfect agreement between raters. Inter-rater reliability for the movement competency screen was 0.79 indicating substantial agreement. Like the FMS and AAA, this movement screener is an example of an assessment tool specifically designed to inform the practitioner of dysfunctional movement and its possible underlying causes to direct very specific exercise interventions.

5.8 CHAPTER SUMMARY

The number of fallers in the older adult population is a major global public health problem. Prevention of falls must span the spectrum of ages and health states within the older population. Intrinsic, or physiological, risk factors for falls have been found in epidemiological and experimental studies. These potentially modifiable factors are many and include impairments in gait function, balance ability, deficits and asymmetries in lower-extremity muscular strength, joint range of movement (ROM) and biomechanical alignment. However, despite this evidence our health care system, and those of other western countries, is primarily focused on discovering treatments and cures for disease rather than prevention. Most falls are the result of the interaction of multiple factors, and the greater number of factors an individual has the greater the individual's propensity to fall. It is important to identify those at risk, and why, to maximise the effectiveness of any prescribed exercise intervention. Ultimately, falling is not a disease per se and the scientific approaches to prevention need to reflect this.

One of the three propositions by the WHO Global Report on Falls Prevention in Older Adults is to improve the assessment of individual factors that increase the likelihood of falls (2). In the community setting, where many people have a higher level of functional ability, factors associated with the transition in status from non-faller to faller need to be better understood. Tools used in other paradigms, such as functional movement and athletic assessment scales, provide valid and reliable measures of physical function in younger more active populations, but this is not necessarily the case in an older adult population. In the next chapter, a systematic review of tools used to objectively measure lower-extremity muscle strength will be presented and discussed.

6 SYSTEMATIC REVIEW: THE OBJECTIVE MEASUREMENT OF LOWER-EXTREMITY MUSCLE STRENGTH IN COMMUNITY-DWELLING OLDER ADULTS

6.1 INTRODUCTION

In the previous chapter, the risk factors for falling in older adults were discussed. Lower-extremity muscle weakness was identified as a potential modifiable factor to reduce the risk of falling in older adults. Muscle strength is required for the successful performance of activities of daily living. Poor muscle strength is associated with an increased risk of falls and loss of physical function in older adults and improving lower leg strength (and balance) has been recommended as a falls prevention strategy (9, 291-293). As a result, the assessment and quantification of muscle strength is an important clinical consideration for patients identified as being at risk falling.

In falls prevention research, many different assessment tools are used to evaluate gait, balance and mobility. However, very few assessment tools directly and objectively measure lower-extremity muscle strength in this older population. Thus, consideration of the measurement properties of existing tools designed to evaluate muscle strength is an important step towards for the accurate identification of muscle weakness in community-dwelling older adults. A systematic review (367) of 54 studies investigating the intra-examiner reliability of hand-held dynamometer to assess muscle strength of the upper extremity concluded that less than half of these studies demonstrated acceptable reliability. Unfortunately, there is also limited data available for the assessment of lower limb muscle groups.

In order for health professionals to be confident of selecting the appropriate outcome measurement tool, a thorough review of the literature is required. Of particular importance for this systematic review was the identification of supporting evidence for each measurement instrument's reliability, measurement error and validity (construct and criterion). The Consensus-based Standards for the Selection of Health Measurement Instruments (COSMIN) provides a methodology and practical framework for selecting the most suitable tools for research and clinical practice (368). In particular, the framework provide guidance for the validity, reliability and feasibility of an outcome measurement tool. Therefore, the aim of this systematic review was to critically appraise, compare and summarise the measurement properties of measurement tools that purport to measure lower-extremity muscle strength in community-dwelling older adults aged over 65 years.

6.2 METHODS

6.2.1 Literature Search

An electronic bibliographic search was conducted from inception until December 2018 using Medline, Embase and Index to Nursing and Allied Health Literature (CINAHL). No restrictions were made by language or year of publication. The search terms used were combined with a validated search filter published by COSMIN (369). The search strategy included combinations of medical subject headings (MeSH) or the equivalent for each database, and free-text word terms. These included: 1) main constructs of interest (muscle strength, lower limb/leg strength, lower extremity strength, ankle strength, knee strength, hip strength, maximal strength); 2) target population (older adults over 65 years, older persons, older people, older adults, community-dwelling, elderly): different terms were used including ‘older’ and ‘elderly’, combined with ‘adult’; 3) type of measurement instrument (tool$, instrument$, measure$, assess$, evaluat$, test, technique$); and 4) measurement properties as per the recommended COSMIN search filter. Searches were then applied and tailored to each individual electronic database. The full strategy of searches undertaken on the Medline database can be found in Appendix Q.

6.2.2 Eligibility Criteria

Studies were included if they met the following eligibility criteria: 1) the measurement tool aimed to measure lower-extremity muscle strength; 2) the study examined the measurement properties of the tools (validity, reliability and/or feasibility); 3) included participants were community-dwelling adults aged 65 years and over without major comorbidity or specific disease subgroups; 4) a description of the method used to measure lower-extremity muscle strength was provided; and 5) the study was published as a full text original article rather than an abstract or conference proceeding.

Studies were excluded if they: 1) recruited patients who were not healthy community-dwelling or had marked disability or concomitant disease such as Parkinson’s Disease, moderate to severe osteoarthritis, brain injury or stroke; 2), did not examine or report measurement properties of strength assessment tools; 3) or evaluated the effectiveness of interventions where measurement tools were used as a baseline and an endpoint only without consideration of validity or reliability.

6.2.3 Study Selection

After completion of database searches, one reviewer independently screened titles and abstracts to identify potentially relevant studies. This process was checked with a second reviewer (SG/JB) for a subset of titles. Following this preliminary screening, full reports of potentially relevant studies were obtained, and two reviewers independently assessed all studies for inclusion/exclusion using a checklist form based on inclusion criteria above (SB with SG/JB) (Appendix R). Where there was disagreement about the inclusion of a study, a third reviewer was consulted.

6.2.4 Evaluation of Methodological Quality

The methodological quality of the included studies was data extracted by one reviewer using the COSMIN checklist 13 (368). Data extraction was checked by a second reviewer (SG/JB). The checklist includes aspects of validity and reliability:: content validity (evidence that the content of a test corresponds to the content of the construct it was designed to cover), construct validity (the degree to which the scores of a tool are consistent with hypotheses or are related to other variables and other tools measuring the same construct), and concurrent validity (evidence that scores from a tool correspond with the gold standard or concurrent external tools conceptually related to the measured construct).

6.2.5 Data Extraction

All reference citations were stored using EndNote web and duplicates were removed. A pre-defined data extraction form was developed for this review (368) (Appendix S). The following information was extracted from the included studies by two reviewers independently: general characteristics of each measurement tool; validity (construct and criterion) and reliability (intraand inter-rater, measurement error) of measurement properties. Where there was disagreement, a third reviewer was consulted.

6.2.6 Data Synthesis

A methodological quality score (very low quality, low, moderate, and high) was obtained by taking the lowest rating of any item (‘worst score counts’). One reviewer assessed the quality of all the included studies and a second reviewer randomly assessed one third of the total number of studies to compare level of agreement. A tool was scored ‘+’ when having a high reliability (intra-class correlation coefficient ≥ 0.70 or Pearson correlation (r) ≥ 0.80), high construct validity (correlation between constructs ≥ 0.50), or high criterion validity (Pearson/Spearman correlation or area under the curve ≥ 0.70)(369).

6.3 RESULTS

After removal of duplicates and title and abstract screening, 251 studies were short-listed as being potentially eligible for inclusion. Two reviewers each screened these independently to check eligibility criteria. Of these, 233 (93%) were excluded for the reasons given in Figure 30. The remaining 18 studies were obtained for full review and quality assessment.

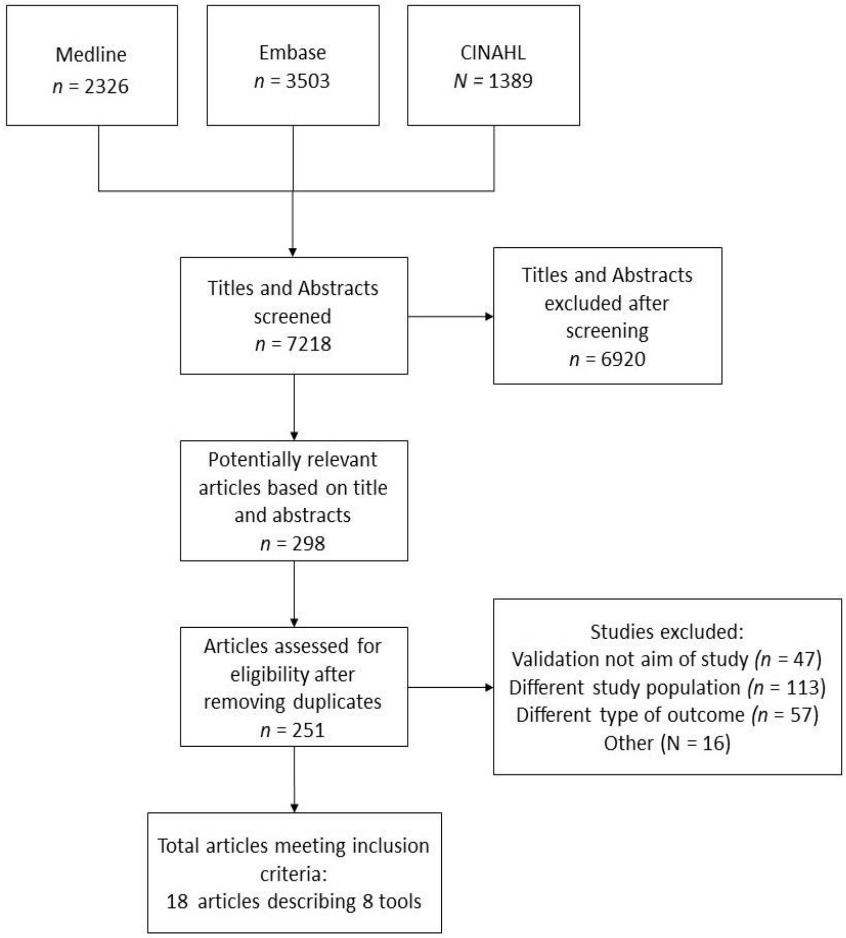


Figure 30 – PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) schematic showing selection procedure of included articles.

The validity and reliability findings of eight different tools reported across 18 studies were assessed. Eight measurement tools were identified in the literature varying from hand-held devices (HHD and Myometer) to large clinic-based machines (isokinetic dynamometer). One tool was a well-known computer game device (Nintendo Wii Board), which is available world-wide at relatively low cost compared to most of the other tools. Two of the tools were adaptations of standard gym-based leg press machines (Keiser A420 and Leg Press Sled), and one tool calculated muscle strength by using the bodyweight squat and a geometric equation (height, weight and leg forward lean angle). Characteristics of the individual studies are presented in the appendices (Appendix T). The grading assigned to each measurement property across all included studies is presented in Table 11.

Table 11 – Grading of Measurement Properties Assessed in the Included Studies (by the COSMIN checklist)

Measurement Property	**Quality of Evidence**		
	Low	**Moderate**	**High**
Reliability (218, 220, 223, 370-383)	2	10	5
Measurement Error (218, 220, 370-384)	3	7	7
Construct Validity (218, 220, 370, 380, 382-384)	-	1	6
Criterion Validity (218, 223, 370, 374, 382-384)	-	1	6

Key: COSMIN = Consensus-based Standards for the Selection of Health Status Measurement Instruments; No Studies were scored 'very low'.

6.3.1 Validity and Reliability

In the 18 included studies, aspects of reliability, measurement error, construct and criterion validity, and feasibility were assessed. The hand-held (six studies) and isokinetic dynamometers (five studies) were the most widely used tools and were found to be a valid, reliable and feasible measure of lower-extremity muscle strength in healthy community-dwelling older adults (218, 220, 223, 370, 371, 379). This review found that other strength measurement tools were also valid and reliable, including the HHD Belt Resisted, Nintendo Wii, Leg Press Sled, Keiser A420 and the Squat and Myometer. The measurement properties for each of these assessments, when applied to an older adult population, can be found in Table 12.

The validity of the included measurement tools were reported across nine different studies. Of these, only five reported both construct and criterion validity in the same study. As shown in Table 12, the isokinetic dynamometer was used as the gold standard for the measurement of lower-extremity muscle strength (102). Four measurement tools (HHD, Leg Press Sled, Nintendo Wii and Squat) were tested for criterion validity by comparison to a gold standard and were found to have moderate to high validity (ICC 0.44 – 0.85; r = 0.57 - 0.86). No criterion validity data was reported for the other four measurement tools. Construct validity was reported in seven studies for HHD, Squat and the Myometer. These tools were shown to have construct validity by comparison to either physical function measures (Lower Extremity Power, Walking Speed and Functional Reach), questionnaires (Physical Functioning Scale) or other HHD protocols. It showed high construct validity values for the Squat (r = 0.88) and moderate to high values for the HHD and Myometer (r = 0.35 – 0.58).

All but one study (Sato et al (384)) aimed to evaluate intra- and/or inter-rater reliability in those undertaken the assessments. Only four measurement tools (HHD, isokinetic dynamometer, Nintendo Wii and Leg Press Sled) were examined for absolute reliability using the standard error of measurement (SEM), with one reliability study (Bohannon (223) .2001) failing to report measurement error. The results of this review found that all measurement tools were reliable with evidence of good correlation between raters (ICC > 0.70). For HHD it showed both high intra-rater reliability (ICC > 0.70) and inter-rater reliability (ICC 0.70 – 0.95) across six studies.

Similar reliability values (ICC 0.74 - 0.98) were found across five studies for the isokinetic dynamometer.

Table 12 - Measurement Properties of Objective Muscle Strength Tools in Community-Dwelling Older Adults

Tool (Reference)	Outcome	Reliability			Validity		Comparator Instrument
		Inter-rater	Intra-rater	Measurement Error	Construct	Criterion	
HHD (218, 220, 223, 370, 371, 379)	ICC 0.70 –0 .95	+	+	SEM < 3.41; LoA 2.4%			
	Criterion ICC .44 – .85 r = 0.57 – 0.86					+/-	Isokinetic Dynamometer*
	Construct r = .38 – .52				+/-		PFS (SF-36)
	r = 0.35 – 0.58				+/-		Other HHD Protocol
HHD (Belt Resisted) (372, 375)	ICC 0.64 – 0.95	+/-	+	LoA - 5.6 – 4.6			
Nintendo Wii Board (382)	ICC 0.90 – 0.98 Criterion ICC > 0.80	+		SEM 9.7 – 13.9%; LoA 20.3 – 28.7%		+	SID
Isokinetic Dynamometer (373, 376, 378, 381, 383)	ICC (intra-rater) .74 – .98;		+/-	SEM ± 16; SEM% 3 – 10%; SRD = -7.2Nm – 5.6Nm; CV < 18%			
	r = .64 – .91		+/-				
Leg Press Sled (385)	ICC > .90;		+	SEM 19.8 – 23.1			
	Criterion r = .74 – .81					+	Isokinetic Dynamometer*

Table 11 Continued

Tool (Reference)	Outcome	Reliability			Validity		Comparator Instrument
		Inter-rater	Intra-rater	Measurement Error	Construct	Criterion	
Keiser A420 Leg Press (377)	ICC > 0.90		+	LoA 1.1% (21.1N)			
Squat (384)	Construct r = .88				+		HHD
	Criterion r = .84					+	Isokinetic Dynamometer*
Myometer (380) (type of HHD device)	ICC .98 – .99		+	CV 4.7 – 7.2%			Isokinetic Dynamometer*
	Construct r = .61				+		LEP
	r = .54				+		WS
	r = .57				+		FR

Key: SEM = Standard Error of Measurement; ICC = Intraclass Correlation Coefficient; r = Pearson's Correlation Coefficient; LoA = Limits of Agreement; SRD = Smallest Real Difference; AUC = Area Under the Curve.

+ = high reliability (ICC ≥ .70), high construct validity (correlation between constructs ≥ 0.50), high concurrent/criterion validity (Pearson Correlation or AUC ≥ .70); - = low reliability (ICC < .70), low validity (correlation between constructs < 0.50), low concurrent/criterion validity (Pearson Correlation or AUC < .70); +/- = Inconsistency in Results.

HHD = Hand-Held Dynamometer; PFS = Physical Functioning Scale; SID = Stationary Isometric Dynamometer; LEP = Lower Extremity Power; WS = Walking Speed; FR = Functional Reach; * = Used as Gold Standard.

The measurement tool with the highest reliability value was the Myometer (ICC 0.98 - 0.99). However, there were no criterion validity data and the construct validity assessment used several physical function tests as the comparators.

Feasibility criteria for these assessment tools were simplicity (ease of use), measurement time, portability of the tool into different settings and affordability of the measurement tool. For quick and accurate assessment and/or screening of lower-extremity muscle strength in community-dwelling older adults, it would be beneficial if the measurement tool was feasible to use in a home, community centre or in general practice.

6.4 DISCUSSION

Ideally, objective tests of lower-extremity muscle strength should be well validated and be proven to be reliable across different populations to provide meaningful data to health professionals. Surprisingly, this review only identified eight objective measurement tools for use in community-dwelling older adults. The results of this review showed that across 18 studies, all eight measurement tools were found to be both valid and reliable in this population. However, in a recent systematic review (386) only three objective measurement tools (HHD, Leg Press and IKD Isokinetic Dynamometer) were identified. Similarly, across nine studies they reported high test-retest reliability for the HHD (ICC > 0.78), across two studies for the leg press (ICC > 0.94) and one study for the isokinetic dynamometer (ICC = from 0.34 to 0.85). However, these results also included testing of the upper body and grip strength measurement data which may have affected the results. This systematic review found more evidence for assessment tools than the recently published review.

Isokinetic Dynamometers are computerised machines that provide static and dynamic measurements of muscle strength (102). They are considered the gold standard reference device and the preferred measurement tool for clinical studies (102, 387). The HHD (ICC 0.44 to 0.85, r 0.57 -0.86), Leg Press Sled (r 0.74 - 0.81) and Squat Method (ICC 0.84) showed moderate to high values when compared to the gold standard. In addition, the Nintendo Wii was compared to a similar device called a Stationary Isometric Dynamometer (ICC 0.80), but this is not considered to be a gold standard (382). Bohannon (221) compared measurements of static knee extension torque using HHD and isokinetic dynamometry in twenty young healthy women. Test-retest results for both devices were shown to be reliable (ICC > 0.90), and the inter-instrument reliability was shown to be fair (ICC = 0.79). It was concluded that under limited circumstances both instruments may be interchangeable. However, the less expensive and more portable HHD may be a practical alternative for the clinical measurement of muscle strength.

After reviewing the included studies' methods, it is evident a lack of homogeneity exists for the application of HHD. In particular, the variations in HHD placement, tester and subject positioning, and the strength and size of the tester. What lends to further heterogeneity is that several different manufacturers of HHD instruments were used to take these measurements. One of the overall limitations was the lack of a standardised measurement protocol when measuring lower-extremity muscle strength. Bohannon (388) also found that various studies revealed a lack of homogeneity in methodology for the application of HHD, which further supports need for using a standard protocol.

A limitation of this systematic review was that not all relevant studies may have been identified. The search was limited to English language manuscripts only. Similar to a previous review, three main biomedical databases were searched, however, other searches of other less commonly used databases (e.g. Science Citation Index) may have citations for other studies. The appraisal of the included literature was based on COSMIN methodology. This is specifically designed to appraise Patient Reported Outcome Measures (PROMS). As such, several aspects of the COSMIN process were adapted to accommodate for the appraisal of a performance-based outcome measurement instrument.

6.5 CONCLUSIONS AND IMPLICATIONS OF KEY FINDINGS

Depending on the setting, the outcome and number of muscle actions requiring testing by any of the measurement tools in this review may provide the health professional with valid and reliable data. Measurement tools providing extensive data (Stationary and Isokinetic Dynamometer) are more suited to clinical settings where quantification of joint torques, force curves and contraction types are required. Considering the cost of isokinetic testing and the impracticality of daily or repeated testing, the HHD, Nintendo Wii and Myometer are considered more suitable, as long as these devices are valid and demonstrate appropriate levels of reliability. Other tools that show high ICC values (including the Leg Press Machine, Keiser A420 and Nintendo Wii Board) are limited in their testing capacity and only provide data on single muscle actions (knee extension) thus not suitable for health professionals who may want to test multiple muscles groups. Scenarios where testing is required away from a clinical setting, and where multiple measurements of several different muscle actions are needed, the HHD, with or without belt resistance, and a Myometer is recommended. Alternatively, for relatively fast and accurate measure of functional strength the simple method proposed by Sato *et al* (384) may be more suitable.

In the next chapter, a systematic review of assessment tools used in fall prevention research will be presented and discussed.

7 SYSTEMATIC REVIEW: FALL RISK ASSESSMENT TOOLS AND THEIR ABILITY TO IDENTIFY MODIFIABLE PHYSICAL IMPAIRMENTS IN COMMUNITY-DWELLING OLDER ADULTS

7.1 INTRODUCTION

In the previous chapters, the increased risk of falling amongst older adults living in the community and the corresponding demand on the NHS was highlighted and discussed. It has been well documented that ageing is associated with physiological and functional decline that can contribute to an increased risk of falling. Chapter 5 discussed these declines and highlighted the need for an appropriate assessment tool for older adults so that health professionals can better design targeted exercise interventions to reverse deficits in muscular strength and physical function. Thus, one of the most important outcomes of an assessment of fall risk is to reliably quantify muscular strength, particularly in the lower-extremity. Such clinical information provides a baseline when the patient presents to a falls clinic or referred for further tests. Subsequently, if an intervention is delivered, the objective quantification of muscle strength allows the health professional to assess changes in muscle strength over time. The previous chapter showed the hand-held dynamometer (HHD) to be a valid, reliable and feasible device for the collection of objective lower-extremity muscle strength measurements. This chapter presents a systematic review of falls assessment tools that have been used to assess community-dwelling older adults after initial screening for falls risk. This chapter will consider whether these falls assessment tools can be used to identify and objectively measure lower-extremity muscle strength and other potentially modifiable physiological factors in this population.

7.2 BACKGROUND

As discussed in Chapter 3, the major intrinsic risk factors for falling include muscle weakness, balance impairments and environmental hazards, several which are modifiable (13, 18, 43, 47-50, 53, 64, 241, 389). A different approach to the assessment of lower-extremity muscle strength, gait and balance impairments may be necessary to better direct an exercise intervention. This comprehensive ‘physiological’ approach contrasts with the ‘disease-oriented’ or ‘population’ approach currently used to direct appropriate interventions. It is important that an assessment tool has the necessary validity to be clinically useful. As per the previous chapter, we know that validity is defined as the extent to which the method/tool measures what it is intended to measure (215). More recently, this definition of validity has been widened to focus on the degree of confidence making inferences about the population the measurement tool was used on (390, 391).

Many high-functioning community-dwelling older adults with few co-morbidities may be going undetected for modifiable physiological fall risk factors. Thus, although considered to be high-functioning, they may still have subtle physiological deficiencies. The joint consensus by the American and British geriatric societies algorithm states that once a person is identified as at risk of falling, or further falls, a multifactorial assessment should be undertaken to direct individualised treatment (313). With reference to modifiable physiological factors, the algorithm pathway recommends individualised exercise interventions to address muscle weakness, gait and balance issues and general physical impairments.

Research has established that participation in regular physical activity and, more specifically, exercises targeting lower extremity strength deficits and balance impairments reduces the risk of falling and improves balance outcomes (55, 62, 64, 392). The health professional requires an appropriate assessment tool to help inform prescription of specific targeted exercises. Better designed assessment tools that directly measure and evaluate physiological impairments are required to enable early intervention and promote a primary and secondary preventative approach to the management of falls. Previous systematic reviews have examined the predictive ability of fall risk assessment tools in different populations and across different age groups (29, 393). However, no review has assessed the ability of fall risk assessment tools to accurately measure potentially modifiable physiological risk factors in this population. Therefore, this systematic review aims to fill this knowledge gap by firstly examining the components included within fall risk assessment tools and secondly to investigate the ability of these tools to identify potentially modifiable physiological impairments.

7.3 METHODS

7.3.1 Objectives

This systematic review aimed to identify fall risk assessment tools that were developed for use with independent community-dwelling older adults, and to summarise these tools' ability to detect potentially modifiable physical impairments. The primary objective was to establish to what extent these tools could identify the following physical impairments: a) gait, b) balance, c) lower-extremity muscle strength deficits, d) biomechanical alignment issues, and e) movement competency. The second objective was to deconstruct the various components of each assessment tool. A careful analysis of the components in combination determined whether each tool met its design requirements.

7.3.2 Search Methods for Identification of Studies

A comprehensive search of the English language medical literature was performed. Key electronic bibliographic resources were searched: AMED (1985-2014), Embase (1947-2014) and Medline (1946-2014). All searches were conducted during March and April 2014. No restrictions were made by year of publication.

The search strategy from a recent review (Appendix A) (394) was adapted for use in this systematic review. Specific search terms were developed for use across the three databases. The search terms used included medical subject headings (MeSH) or the equivalent, and text word terms used in combination (i.e. accidental falls, falls or faller, geriatric or older or elderly, risk assessment, assessment tool, community etc).

The specific names of published or well-known risk assessment screening tools used in this population were also added to the search terms. The reference sections in all identified articles were examined to identify other relevant articles, including publications with modifications to existing screening tools. Data were extracted by the author using a predefined data extraction form (Table 13).

Table 13- Data extraction form

Number	Description
1	Name of assessment tool
2	Developer/Author Rather than who developed it (author)
3	Responses: • Clinician 'subjective' assessment • Clinical 'objective' assessment • Self-report
4	Measurement: • Gait • Balance • Mobility • Reach • Postural Sway • Change of Direction • Biomechanical Alignment • Lower-extremity Strength
5	Specialist training: (yes/no/recommended)
6	How items selected: (intuition/other studies etc.)
7	Format of questions/scales • Yes-No (binary) • Likert/Ordinal Scale • Other
8	Time to complete
9	Cut-off point/s for level of risk presented/suggested (Yes-No, if Yes describe)
10	Specificity
11	Sensitivity

7.3.3 Criteria for Considering Studies for This Review

A study met the needs of this review if it fulfilled the following criteria:

- it was developed, evaluated and/or tested a fall risk assessment tool;
- it clearly explained why the tool was developed;

- it included a subjective and/or objective measure of gait and balance, lower-extremity muscle strength, mobility, physical function, biomechanical alignment and movement competency;
- it was specifically designed to assess community-dwelling older adults.

Additional information in the form of psychometric data (sensitivity, specificity) was also extracted. Studies were excluded if they were designed for adults younger than 60 years or designed for a different setting where the participants were not independently living in a community setting (long-term care facilities, hospitals, homebound etc.).

7.4 RESULTS

Searching the electronic databases yielded 362 citations. A search of reference sections in the identified articles did not yield any further references. Initial screening excluded 311 articles for the reasons given in Figure 30. From those remaining articles, 51 were fully assessed against the criteria for including studies for this review. In total, 25 studies met the inclusion criteria, while the remaining 26 studies were excluded after full review (see Figure 30).

7.4.1 Assessment Tool Development Characteristics

A list of abbreviations used throughout this systematic review are presented in Table 14. A total of 16 assessment tools were included. The findings regarding development characteristics for each tool are summarised in Table 15. Of these, 13 assessment tools were designed for older adults in a community setting and three were designed for use in a combination of settings but have been widely used with older adults. Of the 16 tools, six were modifications of published existing tools and for three tools, it was not clear how they were developed. The remaining five tools were developed by a multi-disciplinary team of experts or based on expert opinion.

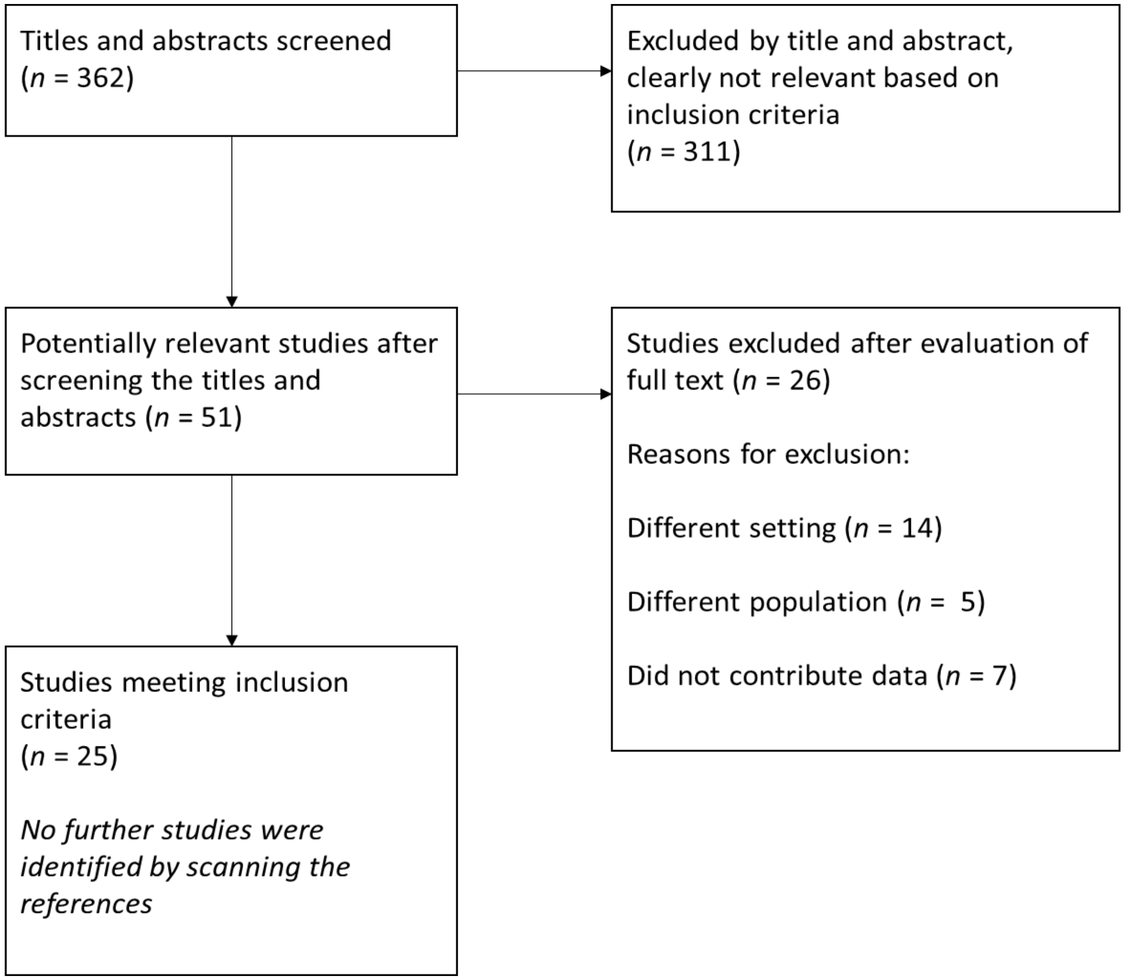


Figure 31. Flow diagram for the selection of studies

The tools were designed to assess gait and balance ability, mobility, lateral stability, stepping and change of direction ability, postural sway, general function, and falls risk. Gait and balance were the most common assessment tool design objectives, with five of the 16 tools having a primary objective to establish falls risk as an outcome in community-dwelling older adults. Specialist practitioner training was required for five of the screening tools. The authors of the remaining studies stated specialist training was not required. It was not possible to establish whether practitioner training was required for the elderly falls screening test assessment tool.

Table 14 **-** List of abbreviations used in this systematic review

Abbreviation	**Definition**
POMA	Performance Oriented Mobility Assessment
FGA	Functional Gait Analysis
TUG	Timed Up & Go Test
LR	Lateral Reach
DFRA	Demura's Fall Risk Assessment
FROP-Com	Fall Risk for Older People in the Community
BBS	Berg Balance Scale
FR Test	Function Reach
BESTest	Balance Evaluation Systems Test
EFST	Elderly Fall Screening Test
FSST	Four Square Step Test
RST	Rapid Step Test
PPA	Physiological Profile Assessment
FAB	Fullerton Advanced Balance Scale
CTSIB	Clinical Test for Sensory Interaction and Balance
FEMBAF	Fast Evaluation of Mobility Balance & Fear

Scoring of Assessment Tools

Six of the assessment tools used objective scoring in the form of time in seconds, distance in centimetres or force in Newtons. Four of the 16 tools employed a dichotomous (yes/no) item response format in all or part of the assessment, with the remainder using either an ordinal or nominal scoring format.

Time to Complete

The length of time to complete an assessment ranged from less than one minute for the functional reach test to thirty minutes (BESTest), with the average duration being 10.5 minutes. For two of the tools, length of time to complete was either not reported (FGA) or conflicted between articles reporting its use (DFRA).

Table 15 - Assessment tool development characteristics

	Articles Reviewed										
Review Parameter	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Parameter Description	**Reference/s**	**Intended Use**	**Objective**	**Specialist Training**	**How Items were selected**	**Format of Questions/Scales**	**Responses**	**Time to Complete (mins)**	**Cut-off Score for high risk**	**Sensitivity**	**Specificity**
Assessment Tool											
POMA	(71, 395, 396)	All	Balance & Gait	No	Research	0-28	Objective	10-15	<19	-	-
FGA	(397)	Community	Gait	No	Modified DGI	0-3	Objective	-	<22/30	100	72
TUG	(331, 342)	All	Functional Mobility	No	Modified GUG	Time (sec)	Objective	<5	≥11 sec	63-87	-
Lateral Reach	(398, 399)	Community	Lateral Stability	No	Intuition & Modified FR	Reach Distance (cm)	Objective	<1	-	-	-
DFRA	(28, 400)	Community	Fall Risk	No	Modified TMIG	Dichotomous	Subjective	-	22	-	-
FROP-Com	(401, 402)	Community	Fall Risk	No	Modified FRHOP	0-3 & Dichotomous	Subjective	<12	18/19	71	56
BBS	(330, 403, 404)	Community	Balance	No	-	0-4	Objective	10-20	<46/56	64-82	90-94
FR Test	(399, 405)	Community	Balance	No	Intuition	Distance (cm)	Objective	<1	-	-	-
BESTest	(406)	Community	Balance	Yes	MD-T/research	6 sections/0-3/Total 108 points	Objective	~30	-	-	-
EFST	(407)	Community	Fall Risk	-	-	1-2/Dichotomous	Both	<10	≥2	83	69
FSST	(408)	Community	Fall Risk	No	Modified RST	Time (sec)	Objective	<5	≥15	85	88-100
RST	(409)	Community	Stepping ability	No	Intuition	Time (sec)	Objective	<2	-	-	-
PPA	(13, 307)	All	Function & Fall Risk	Yes	Intuition	-3 - +3 (z-score)	Objective	10-15	<0	75	-
FAB	(410, 411)	Community	Balance/Fall Risk	Yes	MD-T/research	0-4 (Categorised)	Objective	10-12	22-24, 13-21 & <13	-	-
CTSIB	(24)	Community	Postural sway	Yes	-	COP (N)	Objective	<5	-	-	-
FEMBAF	(412)	Community	Fall Risk/Physical Performance/Fear	Yes	Intuition	Dichotomous & 1-3	Both	<15	<35	-	-

NA= Not Applicable; NR = Not Reported; MD-T = Multi-disciplinary Team; FRHOP = Falls Risk for Hospitalised Older People; COD = Change of Direction; RST = Rapid Step Test; CTSIB = Clinical Test Sensory Interaction for Balance; COP (N) = Centre of Pressure (Newtons of Force); POMA = Performance Oriented Mobility Assessment; FGA = Functional Gait Analysis; TUG = Timed Up & Go Test; BESTest = Balance Evaluation Systems Test; DFRA = Demura's Fall Risk Assessment; FROP-Com = Fall Risk for Older People in the Community; BBS = Berg Balance Scale; FR = Functional Reach; FFS = Fear of Falling Scale; EFST = Elderly Fall Screening Test; FSST = Four Square Step Test; RST = Rapid Step Test; PPA = Physiological Profile Approach; FAB = Fullerton Advanced Balance Scale; FEMBAF = Fast Evaluation of Mobility Balance & Fear;

7.4.2 Assessment Tool Measurement Characteristics

The physiological risk factors most commonly screened for were balance ability and general function, one or both of which were included in 14 (87%) different tools. However, only six (38%) assessment tools simultaneously assessed both balance ability and physical function (POMA; DFRA; BESTest; EFST; FROP-Com; FAB). Other risk factors included gait function, functional (or forward) and lateral reach distances, change of direction ability, postural control/sway and lower-extremity muscle force. Only the PPA objectively assessed lower-extremity muscle force, which was limited to only three major muscle actions (ankle dorsiflexion, knee extension and flexion) where a possible maximum of ten muscle actions can be measured. Similarly, the BESTest tool assessed for biomechanical postural alignment, but only the centre of mass was assessed and only in the frontal plane. None of the assessment tools in this review were considered to objectively or subjectively assess the quality of a person's movement, defined in this context by the author as movement competency.

Assessment tool measurement characteristics are presented in Table 15. Most of the assessment tools (15; 94%) were scored by a health professional observing and then rating a person performing various physical tasks. Of these 15, four tools were compiled of assessment results by observation and the use of a questionnaire. There were 11 (69%) tools which used only observation as a means of gathering results, with only the DFRA tool being solely questionnaire based.

Table 16. Description of components included in falls risk assessment tools

Screening Tools	Measurement Categories									
	Questionnaire	Observations	Balance Confidence	Balance Ability	General Function	Gait Function	Reach Distance	Postural Sway/Control	Change of Direction	Muscle Force Testing
POMA		•		•		•				
FGA		•			•	•				
TUG		•			•					
LR Test		•		•			•			
DFRA	•									
FROP-Com	•	•		•	•	•				
BBS		•		•						
FR Test		•		•			•			
BESTest		•		•	•	•		•		
EFST	•	•	•	•	•	•				
FSST		•			•				•	
RST		•			•					
PPA	•	•		•				•		•
FAB		•		•	•		•	•		
CTSIB		•		•				•		
FEMBAF	•	•	•		•					

Key: POMA = Performance Oriented Mobility Assessment; FGA = Functional Gait Analysis; TUG = Timed Up & Go Test; BESTest = Balance Evaluation Systems Test; DFRA = Demura's Fall Risk Assessment; FROP-Com = Fall Risk for Older People in the Community; BBS = Berg Balance Scale; FR = Functional Reach; FFS = Fear of Falling Scale; EFST = Elderly Fall Screening Test; FSST = Four Square Step Test; RST = Rapid Step Test; PPA; PPA = Physiological Profile Approach; FAB = Fullerton Advanced Balance Scale; FEMBAF = Fast Evaluation of Mobility Balance & Fear; CTSIB = Clinical Test for Sensory Interaction and Balance;

7.5 DISCUSSION

The aim of this systematic review was to identify different fall risk assessment tools that were developed for use with community-dwelling older adults, and to then examine the ability of these tools to detect potentially modifiable physical impairments in this population. The early identification of these risk factors, and the design of an appropriate assessment tool, is essential to highlight any factor that may be associated with poor physical performance and to help determine the most appropriate exercise intervention.

7.5.1 The Assessment of gait, balance and mobility

In this review, a total of 16 assessment tools were identified. The assessment of gait, balance and mobility were the most common aims, with five of the 16 tools having a primary aim to establish falls risk as an outcome measure in community-dwelling older adults. For the tools designed to discriminate between high and low risk of falling, there were some impressive psychometric values. For example, a study by Dite & Temple (408) using the FSST cut-off time of ≤15s for walking on older adults over the age of 65, showed a sensitivity of 85%, a specificity of 88% to 100%, and a positive predictive value of 86%. In another study where the authors chose a cut-off score of ≤2 out of a possible score of 5, the EFST was found to have 83% sensitivity and 68% specificity in functionally independent adults aged over 60 years. (407).

Most assessment tools identified in this review have established cut-off scores to discriminate between high and low falls risk in older adults. Out of the 16 identified assessment tools, 13 used cut-off scores suggesting they were originally designed as a screen to identify people at high risk of falling, rather than a comprehensive assessment of falls risk and physiological factors contributing to that risk. However, only seven were originally designed for that purpose according to the tool developers. The remaining tools were originally developed to assess either functional mobility in frail older adults (TUG), balance ability (BBS; POMA) or gait ability (FGA; POMA), while three were specifically designed both to predict and to identify physiological impairments (FEMBAF; FAB; PPA).

In a review by Lamb *et al* (394), the assessment tools most commonly used in the community setting after a person had been identified through an initial falls screening were the TUG (331), the BBS (330) and the functional reach test (405). Several factors in favour of these physical function tests are the quickness and ease at which they can be implemented with little or no specialist training, low cost and accessibility. Furthermore, the tests have been proved reliable and valid with patients' scores improving over the course of therapy (405). However, although these tools do provide standard measures of physical ability, they do not provide detailed information about why a person may perform poorly in these tests.

Population-level screening and multifactorial risk assessments set out to identify those older adults who are at greater risk of a fall, and to assess the intrinsic and extrinsic factors that may contribute towards a fall, e.g. such as multiple medications, vision impairments and neurological disorders. This review found that although falls screening tools could identify a particular risk domain, such as muscle weakness, none could identify any potentially modifiable causes of that muscle weakness. For example, the functional reach test can measure and identify a person's limited forward reach, but not the underlying reasons for this limitation such as poor muscle flexibility and/or joint mobility. This is, in part, due to the aims of the assessments that are used at this stage. For example, several of the most popular and most widely used assessments are tools that establish fall risk by quantifying functional status, rather than identifying why a person presents with specific muscle weakness, imbalances and impairments. This is supported by the many studies describing these assessment tools as having discriminating properties to predict fallers in stroke patients (332, 399, 413-415), Parkinson's disease (333, 416, 417), and community-dwelling older adults (24, 336, 340, 347, 418, 419).

Two of the tools identified in this review (BBS and TUG) were widely used in fall prevention and were considered to be most relevant to this systematic review. Both of these tools have been used extensively in different populations and across different settings and are therefore reviewed in greater detail in the following sections.

The Berg Balance Scale (BBS)

The BBS is one of the best-known and most widely used balance measurement tools (420) (Appendix G). It consists of 14 tasks quantified on a 5-point scale and evaluates the ability to maintain positions of increasing difficulty by decreasing the base of support, from sitting to standing, to close standing, to tandem standing and finally to standing on one leg. In a review by Lamb *et al* (421) examining UK falls clinics, it was reported that the BBS was being used as both a screening and an assessment tool.

Although well established as a reliable and valid measure of balance in a variety of older adult populations (404, 414, 417), the BBS has several limitations. For example, ceiling effects have been observed when the highest score on the BBS scale does not capture or discriminate between differences in the upper end of the attribute being measured (24, 416, 422, 423). In other words, a person can achieve a perfect score on the BBS yet still have specific balance impairments that need addressing. There is a possibility that, despite reporting task performance, fallers may not have had a sufficient reduction in balance ability that is detectable by these tests, further indicating that falling could have been caused by multiple factors other than from poor balance alone. If this is the case, then their use in active community-dwelling older adults must be questioned. This is supported by a study by Leddy *et al* (423) who observed ceiling effects in subjects with Parkinson's disease in which 10% of those tested had perfect scores, including one faller, and 46% of those tested had scores in the top 10% of the test, including five fallers. Similarly, a systematic review (332) appraising the BBS in stroke patients concluded that the BBS is a psychometrically sound measure of balance impairment but recommended that clinicians use the BBS in conjunction with other balance measures.

The Timed Up & Go Test (TUG)

Another widely used functional ability measure, the TUG test, is a quantitative measure of the Get Up and Go test originally developed by Mathias *et al* (424) (Appendix F). The TUG assesses the amount of time it takes a person to rise from a chair, walk threemeters (m), turn around, walk back, and return to a sitting position in a chair (331). As a result, it assesses the transitional movements of standing up and sitting down, and neuromuscular components of physical performance such as strength, power and balance (425). Originally designed to assess functional mobility in frail community-dwelling older adults, it is more commonly used as a screening tool to establish fall risk, and also used as an assessment to evaluate a patient's gait and balance status (3).

The TUG is validated for use with healthy community-dwelling older adults (340, 347, 399), and patients with a variety of conditions such as Parkinson's disease (426), stroke (427), and hip osteoarthritis (428). Performance of the TUG is also poorer in at-risk populations and those with cognitive impairments (429). Cut-off scores for fall risk vary based on the population tested with >10s for patients with hip osteoarthritis, >7.95s (430) and >11.5s (431) in older adults with Parkinson's disease, and >13.5s for community-dwelling older adults (331, 347, 428). Impressive reliability and validity values have been reported for the TUG, but several authors have cautioned against its use in clinical practice (24, 432). Furthermore, several systematic reviews (432-434) have been published on the discriminative ability of the TUG in community-dwelling older adults. Rydwik *et al* (434) concluded the TUG should not be used to discriminate between older adults with high or low falls risk. Beauchet *et al* (433) stated that although retrospective studies found the TUG time performance is associated with a past history of falls, its predictive ability for future falls remains limited. Another more recent review by Schoene *et al* (432) also concluded the TUG is not a useful tool for discriminating between fallers and non-fallers in healthy community-dwelling older adults, but is of more value in less-healthy, lower-functioning older adults.

Interestingly, the TUG has been described as a test of basic functional ability in frail elderly persons (331), a performance measure of balance and gait (24, 347), as well as a test of mobility (298). The TUG is recommended as a routine screening test for falls in the guidelines published by the American/British Geriatrics Societies (15). On the other hand, the published guidance by NICE recommend the TUG test is used as a further assessment of gait and balance issues. Confusingly, it seems the TUG, the BBS, FRAT and many similar tools, are being used both for screening and for more detailed assessment purposes (254, 393, 421). Furthermore, the NICE guidance stated many measures of gait and balance used in falls clinics did not meet the criteria for the definition as set out in the ProFaNE Taxonomy (75).

Screening and assessments have distinct definitions and placed in different sections of the fall prevention algorithm. Consequently, a tool used for screening purposes should be distinctly different to one used for assessment purposes.

Dichotomous and Cut-off scoring

In this review, four assessment tools (DFRA; FROP-Com; EFST: FEMBAF) used dichotomous scoring, suggesting these tools may be more useful to differentiate the various levels of physical performance rather than the identification of modifiable impairments. In addition, of the 16 tools in this review, 12 used cut-off points to categorise older adults either into high or low risk of sustaining a fall. At the MFRA/MFFP stage, once high risk is established, further risk assessment may be warranted to identify which domains need targeting. However, it is also at this stage where identification of potential modifiable physical factors is recommended, rather than a further classification of fall risk status (15). In fact, several studies and reviews have cast doubt on the ability of these tools to accurately predict fallers in healthy community-dwelling older adults, reinforcing the notion that falling is difficult to predict and also implying that fall risk at the MRFA stage cannot be adequately assessed. For example, a study by Brauer *et al* (399) examined the ability of three laboratory tasks and four clinical balance tests (BBS; LR; FR; Step Up Test) to measure physical function to predict fallers in one hundred community-dwelling older women who had not reported a fall in the last month (65-86 years, mean age 73, SD ± 5 years). The authors not only concluded that the clinical balance tests were not able to predict fallers in this population, but also that alone no individual test provided a better prediction of fallers and in so doing illustrating the multifaceted nature of the decline in balance ability. Furthermore, a study by Boulgarides *et al* (24) using a similar sample concluded that combining five balance tests (BBS; TUG; CTSIB; Dynamic Gait Index; Limits of Stability) with several health and demographic factors only correctly predicted one of 20 falls (p = 0.45).

Whereas certain tests require the patient to perform single tasks not necessarily specific to everyday human function (forward reach; lateral reach; single leg balance), others (POMA; TUG; BBS) require the performance of multiple functional tasks which are closely associated with activities of daily living (ADL) (e.g. stair climbing; picking up objects; getting up from a chair; walking). Although these tests provide an indication of a person's balance status, they too are limited in their ability to detect changes in function and to identify underlying mechanisms behind poor physical conditioning and performance. The results of this review show tools such as the POMA, FGA, FROP-Com, BESTest and EFTS are primarily concerned with predicting who is more likely to fall. They do not appear to assess and quantify gait and balance impairments.

7.5.2 The Assessment & Measurement of Lower-extremity Muscle Strength

Due to the importance of maintaining lower-extremity muscle strength during ageing (14, 47, 263, 271, 282-285, 306, 435, 436), and its contribution to fall risk, its measurement is important in evaluating the functional status of individuals in identifying and treating those at risk for mobility problems and frailty (20, 50, 437-441). The finding that muscular weakness is a risk factor for falls (12-14, 43, 47, 48, 50, 52, 250, 285, 442) poses the broader question of whether strength training prevent falls. A muscle strength assessment tool would need to have the capacity to directly and reliably measure strength in the lower extremity, not just segments of the lower-extremity (knee extensors, knee to ankle; hip to knee etc.). On account of the compensatory nature of the human movement system (see Chapter 3), identification of any impairments associated with it are essential for the targeting of an individualised exercise intervention.

Surprisingly, apart from the PPA no other assessment tool objectively measured lower-extremity muscle strength (Table 16). Furthermore, the tools overall appeared to conceptualise lower-extremity muscle strength as the ability to accomplish some form of functional task, with performance being measured either on a nominal (dichotomous) or ordinal scale. Several problems arise when this concept of a scaled measurement is used in isolation on community-dwelling older adults. The first and most apparent in effect is its tendency to produce a ceiling/floor phenomenon. For example, patients who score well and complete a TUG test (below a set cut-off score) may have lower-extremity strength deficits, biomechanical alignment issues and/or movement impairments that will be missed. The underlying physical impairments that are missed could serve as an indicator for fall risk. This 'miss factor' is also apparent in cases where older seemingly well-functioning adults take longer to complete the test (i.e. >11 seconds) – evidence that the test fails to highlight where they may be problems in other areas associated with fall risk, such as poor balance control and/or poor biomechanical alignment. The TUG test may well identify an older adult as having poor functional status. It does not however provide any information regarding the underlying physical impairment causing the decline in function.

The second apparent effect of an assessment tool limited to measuring only one construct of lower-extremity muscle strength can be found in its lack of responsiveness or sensitivity to change. Tools such as the POMA, BBS and FGA all purport to measure lower-extremity muscular strength. However, insofar as they all default to indexing and/or dichotomising physical abilities in higher functioning individuals, they also tend to desensitise the assessment tool to changes in performance. The BBS provides an example of this phenomenon when the measure being used (e.g. index; Likert scale; 'Yes/No') does not fit with the construct being measured (human physical performance). For example, independent community-dwelling older adults would be expected to be able to stand safely for two minutes, be able to sit safely for two minutes and be able to sit safely with minimal use of the hands. Thus, when this has been demonstrated to the assessor, the tool becomes redundant at detecting small, but meaningful, changes in performance. Similarly, the TUG, quoted as one of the best performing fall risk tools for this population (443), assesses the time it takes to rise from a standard chair, walk three meters, return and sit down. Many healthy community-dwelling older adults would be expected to complete this assessment below the 11 second cut-off time, but again small changes in performance, other than time to complete, are missed. Multiple fall risk factors that may be present in this population would go undetected if the participant performs below the cut-off time, further limiting the sensitivity to change of the tool. Therefore, although these tools may work as good screening instruments, they offer limited information to assist with intervention planning.

Due to the link between muscle strength and risk of falling in the elderly (12, 73, 251, 444) it would seem logical and necessary to include this measure as part of a comprehensive assessment tool. However, in fall prevention research the concept of measuring lower-extremity muscle strength is poorly delineated. Moreover, geriatric assessment tools, that purport to measure strength (BESTest; TUG; PPA; POMA and 30sCRT), need to clearly explain the underlying principles; that is, does a given assessment tool measure functional, isometric, isotonic strength or some other aspect of the wide-ranging construct of strength? Indeed, strength can be conceptualised as the ability to move the whole body/body part against gravity, the ability to accomplish a functional task, the ability to generate muscular force, or the ability to lift a certain weight in a certain time and/or distance. It seems sensible then that an assessment tool developed for the identification of a modifiable risk factor such as muscle weakness should also, by definition, have the ability to measure most if not all constructs of strength.

Interestingly, one aspect of fall prevention which has received little attention is the role of muscle weakness in the ability to recover from a trip or fall. Most, if not all, interventions focus on improving strength to overcome gait and balance impairments typical with ageing. It is hypothesised that greater lower-extremity muscle strength increases a person's reaction and evasive ability to overcome an obstacle. However, another theory assesses the patient's ability to recover from an off-balance situation so that a fall can be prevented. Both views imply that older adults are at higher risk of falling not because they trip or stumble but rather due to their inability to successfully recover from their loss of balance. Cross-sectional studies in males indicate that isometric and concentric strength levels peak between the second and third decades and remain unchanged until the fourth or fifth decade, and start to decline at a rate of 12-15% up to the eighth decade (266). Indeed, muscular strength is pivotal in many daily activities such as getting in/out of a chair and ascending/descending stairs, and contributes to maintaining stability in static and dynamic conditions (46). Considering this evidence, the measurement and maintenance of muscle strength needs to become an important element of fall prevention in community-dwelling older adults. This is an area that clearly needs more research.

If an association exists between lower-extremity muscular strength and falling in older adults, then this needs to be reflected in fall risk assessment tools. Other than the PPA by Lord and colleagues (307), assessment tools identified in this review do not have the ability to direct an adequate strength training intervention. They do not directly quantify lower-extremity muscular strength, and neither do they identify which muscle group/s need strengthening. In their short-fallings they raise the question of how an intervention can be targeted and a person's muscular strength deficits modified without first knowing what they are? Clearly it is important that a direct measurement of lower-extremity muscular strength forms part of a comprehensive assessment following a screening test, with a subsequent patient-specific strength training intervention based on the results of that test.

7.5.3 Objective Measures of Physical Function

Each patient group setting has associated risk factors which should determine which assessment tool is appropriate to use. Generally, community-dwelling older adults, by their very description, are physically more active, higher functioning and more confident than their institutionalised counterparts. Therefore, a measure of movement competency would be advantageous as well as an objective measure of lower-extremity muscle action strength, balance ability and mobility to comprehensively capture and identify modifiable fall risk factors. A risk assessment/screening tool measuring movement and mobility becomes arbitrary if the results only serve to quantify functional status. An effort to query and outline the best exercise programme for fallsprevention really depends on the design of a suitable assessment tool that responds to the specific needs and requirements of each individual in that exercise programme.

Because human movement is three dimensional (sagittal, frontal and transverse), the continued use of assessment tools which measure only one dimension, such as the BESTest, LR and FR, can potentially miss fall risk factors which may be present in the remaining planes of movement. Movement can be dominant in one of these dimensions, but no motion occurs strictly in one plane of motion (84). Indeed a prospective study by Brauer (399) found that the BBS, FR, Lateral Reach (LR) and a Step-Up Test were unable to predict fallers in community-dwelling older adults. Other authors (343, 445) have also identified the LR and FR screening tools to be weak measures of stability limits in older adults. It is not surprising that these, and other similar tools, have failed to predict fallers or give detailed information of underlying causal factors. Although quick, cheap and easily administered some of these risk assessment tools are not adequately designed to identify the frequently reported physiological factors associated with falling in a high-functioning/active older adult population. The fact that none of the assessment tools in this review included measures of biomechanical alignment and/or movement competency, with only one tool (PPA) directly measuring lower-extremity muscle strength, suggests that these tools are probably better suited for initial screening or use with lower-functioning and/or institutionalised frailer older adults.

7.5.4 Strengths & Limitations

This is the first systematic review to consider the design characteristics of fall risk assessments used in community-dwelling older adults. The search strategy was adapted from a landmark review (421) in the field of falls risk and therefore it is likely to capture most of the relevant literature. Despite these strengths, there are several limitations to this review which need to be highlighted. Firstly, due to resource limitations (time, money etc.), non-English language articles and grey literature were excluded from this review. As a result, it is possible that several potentially relevant articles may have been missed resulting in search bias. Secondly, abstracts and titles were screened, including the final inclusion/exclusion decision, by one author. Data abstraction was also complete by one author, however, analysis was reviewed and revised by three authors.

7.6 CHAPTER SUMMARY

The aim of this review was to identify fall risk assessment tools that were developed for use on healthy community-dwelling older adults, and to summarise these tools' ability to detect modifiable physical impairments in this population. Assessment tools identified in this review appear to conceptualise lower-extremity muscle strength as the ability to accomplish some form of functional task, with performance being measured either on a nominal (dichotomous) or ordinal scale. In isolation, arguably this scoring method is better suited to determine mobility/movement impairments, and a direct measurement should be favoured to identify muscle strength deficits.

The goal of using a fall risk assessment tool is to discriminate high and low risks of a fall and to highlight areas for further investigation. According to the American Geriatric Society/British

Geriatric Society guideline, assessing fall risk (i.e. screening) is a distinct process from a more intensive assessment and intervention (15). Conversely, the ProFaNE Taxonomy Domain 3 (C200) (75) does not make this distinction. It puts forward the notion of screening as short test to determine an older adult's risk of falling, and it puts forward the notion of the assessment process as a diagnostic test to determine an older adult's risk of falling. It does not differentiate between the screening and assessment process. The latter definitions may explain why most of the assessment tools' objectives are to predict, categorise and/or distinguish fallers, rather than to identify underlying causes of falls.

The early detection of known modifiable physiological risk factors, and the design of an appropriate assessment tool to identify them, is essential if the objective is to reduce falling through targeted intervention. If the intervention involves exercise, then it is important that an assessment process determines what specific areas of the body need modifying for each individual. Such an assessment, complete with other constructs of human physical performance (e.g. strength, balance, gait etc.), need to be tested in a clinical setting. The results of this review, then, strengthen support for these recommendations and reinforce the need to adopt a multifactorial and multi-disciplinary approach that uses and applies all the constructs associated with human physical performance to fall risk assessments in community-dwelling older adults.

The conceptual framework underpinning injury risk factors in strength and cnditioning science, and assessment tools such as the PDT-Com, may go some way to advancing current practices in fall prevention research. The next chapter outlines the underlying conceptual framework and development process of the PDT-Com assessment tool. Most importantly, it outlines where and how the PDT-Com assessment tool has been designed to meet and identify specific areas of poor physical performance.

8 REFERENCE VALUES FOR ISOMETRIC LOWER-EXTREMITY MUSCLE FORCE MEASUREMENTS OBTAINED BY HAND-HELD DYNAMOMETER

8.1 INTRODUCTION

Chapters 3 and 4 outlined the underlying concepts of the PDT-Com assessment, its scoring criteria and interpretation. It has since been adapted to identify community-dwelling older adults' physical impairments, muscle strength deficits and movement dysfunctions. Reference values allow clinicians and other health professionals to use HHD data they have obtained to allow meaningful comparisons with other individuals. However, to identify muscle strength deficits in this population a scoring system based on reference values first needs to be established.

Measurement instruments or assessment tools used for research or clinical applications must have their reliability established (446). Reliability is defined as the extent to which measurements can be replicated (447). The intraclass correlation coefficient (ICC) is the preferred method to test the reliability of the HHD in this study. However, there are different forms of ICC that can give different results on the same set of data. In this study, the use of a Two-way Mixed Effects Model (ICC $_{3,1}$) was chosen because the test-retest is done using a single measurement with no requirement to generalise to other raters of similar characteristics (448). The use of a Pearson's and/or Spearman's correlation coefficient in this instance would be incorrect because these correlations do not consider systematic error. Similarly, the Cohen's Kappa statistic can be used to examine reliability, but this is the preferred method for use with ordinal and dichotomous/nominal data (449, 450). Historically, other methods such as Bland-Altman plot and the paired t-test (451) have been used to test reliability. However, these methods are primarily used to analyse level of agreement.

This chapter details the experimental study conducted in order to firstly, quantify the test re-test reliability of hand-held dynamometry (HHD) by two raters during a single session and to secondly, collect reference data for ten lower-extremity muscle actions in a small sample of healthy community-dwelling older adults.

8.2 ABSTRACT

Background: The extent of a person's muscle strength impairment can be objectively quantified by comparing data collected by way of HHD to reference, or normative, values from unimpaired individuals. Such values are essential in assessing how community-dwelling older adults' muscle strength is impaired compared to a healthy, asymptomatic population. As stated in Chapter 5, if falls reduction is the outcome of interest then the early detection of known modifiable physiological risk factors is essential to determine who is at risk and why. A novel assessment procedure (the Performance Deficit Test – PDT-Com) has been developed to identify community-dwelling older adults' physical impairments, muscle strength deficits and movement dysfunctions. However, to identify muscle strength deficits in this population a scoring system based on reference values first needs to be established. Therefore, the purpose of this study is to collect values of lower-extremity isometric muscle force values using HHD from ten lower-extremity muscle actions in a sample of healthy adults.

Subjects: Seventy-five healthy asymptomatic community-dwelling older adults participated in this study (female *n* = 50, mean age (*SD*) = 65 (6), range 60-85 years; male *n* = 25, mean age (*SD*) = 67 (7), range 60-87 years).

Methods: Gender, age, height, weight and dominant side were recorded. Ten lower-extremity muscle actions (hip adduction, hip abduction, hip extension, hip flexion, knee flexion, knee extension, plantar flexion, inversion, dorsi flexion, and eversion) were tested for isometric force by four raters (male *n* = 2; female *n* = 2) using HHD.

Results: The measurements were found to be reliable. Mean and standard deviation force outputs for ten lower-extremity muscle actions are presented grouped by gender and dominant/non-dominant side. The PDT-Com scoring system is presented grouped by gender and dominant/non-dominant side.

Conclusions: Objective measures of lower-extremity muscle strength can be reliably collected using HHD, and these values can be used to establish a scoring system for the PDT-Com assessment. Data collected using the PDT-Com will enable health professionals to compare a person's lower-extremity muscular strength deficits relative to healthy subjects of the same age group, gender and dominant/non-dominant side.

8.3 BACKGROUND

As discussed, the prevention of falls and mobility-related disability among community-dwelling older adults is an urgent public health challenge in the UK. Many risk factors for falls have been identified, with lower-extremity muscle weakness frequently reported as a risk factor which has the potential to be influenced with an individualised exercise intervention (14, 54, 55, 64, 316). Falls in older adults can now be predicted by assessing physiological risk factors such as muscular strength deficits, balance ability and gait function (243, 452). The extent of a person's muscle strength deficit can be objectively quantified using the results of hand-held dynamometry (HHD) testing in comparison to reference, or normative, values from healthy unimpaired individuals. Such values are essential in quantifying how much a person's muscle strength is impaired. Although previous research has presented values of force using HHD (99, 258, 453-461), their effectiveness in identifying weakness and dysfunction has been limited because of the low number of muscle actions/groups tested, the several different HHD devices being used and the heterogeneity of the participants.

As fall prevention strategies move towards physiological adaptations (e.g. increasing lower-extremity muscle strength) the measurement of physical function becomes increasingly important. A recent systematic review (Chapter 7) highlighted that current assessment tools are more suited for determining an older adult's likelihood of a fall than quantifying functional status. It highlighted the need for an assessment tool with the ability to identify individual lower-extremity muscle strength deficits, gait and balance issues and movement impairments to direct an exercise intervention. The PDT-Com advances this concept and presents a framework for such a tool. It does however require a scoring system to offer the health professional meaningful and comparable data. Therefore, the purpose of this study is to collect reference values of lower-extremity muscle force from 10 muscle actions in asymptomatic community-dwelling older adults and to use these values to establish a scoring system for the PDT-Com assessment protocol.

8.4 METHODS

8.4.1 Subjects

A convenience sample of independent community-dwelling older adults was invited from the local community to participate in this study (Female n = 50; Male n = 25). A large sample size would be more representative of the target population, however, pragmatically 75 participants was the maximum that could be achieved with the limited resources available. Random sampling would have been ideal but was not feasible because it was not possible to identify eligible people and then use a random sampling strategy (450). The female subjects' mean age was 65 years (*SD* = 6; range = 60-85), and the male subject's mean age was 67 years (*SD* = 7; range = 60-87) (Table 17). Volunteers were recruited from voluntary organisations, local yoga and Tai Chi classes, independent living facilities and word of mouth in the areas of Warwickshire and Northamptonshire. Inclusion criteria were adults 60 years and over, independently living in the community who regularly ventured outdoors without using a walking aid. Subjects were excluded from this study if they resided in nursing homes or suffered from any of the following conditions: acute rheumatoid arthritis; heart disease; marked cognitive impairment; multiple sclerosis; Parkinson's disease; or if they had been diagnosed with osteoporosis.

Subjects who agreed to participate in the study provided written informed consent. Full ethical approval by Biomedical and Scientific Research Ethics Committee was obtained for the study (REGO-2014-708 – Appendix C). All subjects were asked to consider and sign a consent form. Gender, age, height and weight were recorded and measured for each subject. The dominant leg (preferred for kicking a ball) for each participant was identified and recorded.

Table 17 - Characteristics of study subjects

	Age (years)		Height (cm)		Weight (kg)	
Gender	**Mean**	***SD***	**Mean**	***SD***	**Mean**	***SD***
F	65.0	6.0	163.5	6.5	63.7	8.7
M	67.0	7.0	177.8	5.3	82.7	8.6

8.4.2 Instrumentation

Force values of 10 lower-extremity muscle actions, defined as the maximal voluntary force that subjects could exert on the HHD under testing conditions, were measured using a calibrated Lafayette Manual Muscle Tester (LIC.01163, Lafayette Instrument Company, Loughborough, Leics, UK) (Figure 31). The HHD was set to read force in Newtons (N); it will measure force to the nearest 0.1 Newton; the upper limit of the HHD exceeds 1200N.

Figure 32 - Lafayette Manual Muscle Tester (LIC.01163, Lafayette Instrument Company, Loughborough, Leics, UK

8.4.3 Procedures

The main author served as the rater for this study and has over ten years full-time musculoskeletal rehabilitation clinic experience, which included extensive experience using HHD. At the time of the testing, the rater was 41 years old with a mass of approximately 900N. Isometric force of 10 lower-extremity muscle actions was measured bilaterally three times and the mean value was calculated. The 10 lower-extremity muscle actions (groups) were hip adduction (adductors), hip abduction (gluteus medius), hip extension (gluteus maximus), hip flexion (psoas), knee flexion (hamstrings), knee extension (quadriceps), ankle plantar flexion (gastrocnemius), ankle inversion (tibialis posterior), ankle dorsi flexion (tibialis anterior), and ankle eversion (peroneals).

Details of the dynamometer placement, limb positions and subject stabilisation are provided in Table 17. The HHD indicated the start and finish points of a five second contraction duration by an audible beep. Standardised instruction and encouragement to achieve a maximal contraction were given, with the rater applying a countering force to oppose the subject's force. There was approximately five seconds between contractions and a minimum of 15 seconds rest between each muscle action test. The rater removed the HHD from the limb after the five seconds and force was recorded. Rest periods were timed using a standard sports stop-watch (Fastime DB3, Astopwatch Ltd., Leics, UK).

Subjects were asked to wear loose fitting clothes and remove their footwear. If required, clothing was adjusted to reveal both ankle joints. A detailed standardised procedure of the PDT-Com assessment can be found in Appendix P.

8.4.4 Statistical Analysis

All statistical analyses were calculated using SPSS (version 21). Data were analysed descriptively. Intra-session reliability of the repeated measurements of each muscle on each subject's dominant side was established by examining the differences in HHD forces from 10 subjects (female n = 5; male n = 5) using analysis of variance (ANOVA), calculating reliability coefficients ($ICC_{3,1}$) and a 95% confidence interval (standard error of measurement). Mean force values and standard deviations were calculated for all muscle actions for both dominant and non-dominant sides for each gender. A two-way paired-samples t-test was used to compare each muscle action, comparing dominant with non-dominant side and gender.

Table 18 - Details of subject position, dynamometer placement and required stabilisation provided for each muscle group tested

Muscle Action	Muscle Group	Type of Test	Limb/Joint Positions	HHD Placement	Stabilisation (if required)
Ankle Inversion	Tibialis Posterior	Make	Foot plantar flexed & everted (turned outwards) with a fully extended knee	Medial aspect of the foot just proximal to the metatarsophalangeal joints	Subject's back supported in an upright position; rater stabilised ankle at distal lateral tibia
Ankle Eversion	Peroneals	Make	Foot plantar flexed & inverted with a fully extended knee	Lateral aspect of foot just proximal to the metatarsophalangeal joints	Subject's back supported in an upright position; rater stabilised ankle at distal medial tibia
Ankle Dorsi flexion	Tibialis Anterior	Make	Foot placed into full plantar flexion with a fully extended knee	Anterior aspect of foot just proximal to the metatarsophalangeal joints	Subject's back supported in an upright position
Ankle Plantar flexion	Triceps Surae	Make	Place foot into dorsi flexion (neutral) with full knee extension	Plantar aspect of foot just proximal to the metatarsophalangeal joints	Subject's back supported in an upright position
Hip Extension	Gluteus Maximus	Make	Hip approx. 45 degrees of flexion; knee fully extended	Posterior surface of the thigh proximal to the knee	Trunk supported by forearms on a therapy table/couch
Knee Flexion	Hamstrings	Make	Knee placed in 60 degrees of flexion	Posterior surface of lower-limb approx. 10cm above transverse line of the malleoli	Apply downwards pressure on the posterior surface of the distal femur
Hip Abduction	Gluteus Medius	Break	Leg in approx. 20 degrees of hip abduction with knee in full extension	Lateral surface of the lower-limb approx. 10cm above transverse line of the malleoli	N/A
Hip Adduction	Adductors	Break	Inner leg approx. 15-20 degrees of hip adduction with knee in full extension	Medial surface of the lower-limb approximately 10cm above the transverse line of the malleoli	Upper-most leg flexed at the hip and knee supporting using the table/floor
Hip Flexion	Iliopsoas	Make	Hip in 60 degrees of Flexion; foot in contact with therapy table/floor	Anterior surface of the thigh proximal to the knee	Arms placed across chest to prevent anchoring of the upper body
Knee Extension	Quadriceps	Make	Leg placed in 90 degrees of knee flexion	Anterior surface of lower-limb approx. 10cm above transverse line of the malleoli	A bolster is placed under the knee of test leg, so foot is not in contact with the floor

8.5 RESULTS

Seventy-five community-dwelling older adults volunteered to take part in this study (Female n = 50; Male n = 25). The age of all participants ranged from 60 – 87 years (Table 17). A summary of statistics that describe the reliability of the HHD measurements is presented in Table 19. All intra-class coefficients were greater than 0.80 indicating almost perfect agreement according to Landis and Koch (462), except plantar flexion ($ICC_{3,1}$ = 0.44, CI 95% -0.11-0.83) and knee extension ($ICC_{3,1}$ = 0.56, CI 95% - 0.08 - 0.94) indicating moderate agreement (462).

Internal consistency was established using The Cronbach's alpha value for the first measurements of each muscle action (α = 0.91). Mean muscle strength values for dominant and non-dominant side are summarised in Tables 20 and 21 respectively.

These data confirm some expected patterns: males were taller than females (height (*SD*) = 177.8 (5.3) cm vs 163.5 (6.5) cm); males weighed more than females (weight (*SD*) = 82.7 (8.6) kg vs 63.7 (8.7) kg). On average, males were older than females (age (*SD*) = 67 (7) years. vs 65 (6) years), and of the 75 participants, 92% were right-side dominant with 8% being left-side dominant.

Men had higher muscle action force output than women scoring consistently higher mean HHD values (F (20, 54) = 6.22, p < .001). However, there were no significant differences (MD 0.40N – 5.35N; p = > 0.05) in muscle action force between the dominant and non-dominant sides in males, except ankle plantar flexion (*MD* = -24.96N; p = 0.01), and knee flexion (*MD* = -9.64N; p = 0.01) (Figure 33). Similarly, there was no significant difference in force output between dominant and non-dominant sides in females, except plantar flexion (*MD* = -10.22N; p = 0.04) (Figure 34). The mean muscle action strength differences between genders for dominant and non-dominant sides are illustrated in Figures 35 and 36 respectively.

Table 19 - Test-Retest Reliability of HHD Measurements of Force Obtained During a Single Session by One Rater

		Mean Force (N)				
Muscle Action	**Side**	**Test 1**	**Test 2**	***ICC (CI 95%)**	***F***	***p***
Ankle Inversion	Right	133.50	135.10	.95 (.82 - .99)	*37.385*	*.001*
Ankle Eversion	Right	130.60	129.20	.95 (.83 - .99)	*38.559*	*.001*
Ankle Dorsiflexion	Right	174.60	182.40	.89 (.58 - .97)	*21.962*	*.001*
Plantar Flexion	Right	304.70	389.00	.44 (-.11 - .83)	*6.489*	*.005*
Hip Extension	Right	188.80	196.90	.95 (.81 - .99)	*43.627*	*.001*
Knee Flexion	Right	106.70	106.70	.96 (.84 - .99)	*40.955*	*.001*
Knee Extension	Right	266.20	333.50	.56 (-.08 - .94)	*14.953*	*.001*
Hip Abduction	Right	125.10	122.70	.97 (.88 - .99)	*56.177*	*.001*
Hip Adduction	Right	110.20	107.50	.93 (.76 - .98)	*25.51*	*.001*
Hip Flexion	Right	180.00	182.40	.82 (.45 - .95)	*9.859*	*.001*

N = Newtons; ICC = Inter-class Correlation Coefficient; * Single Measures;

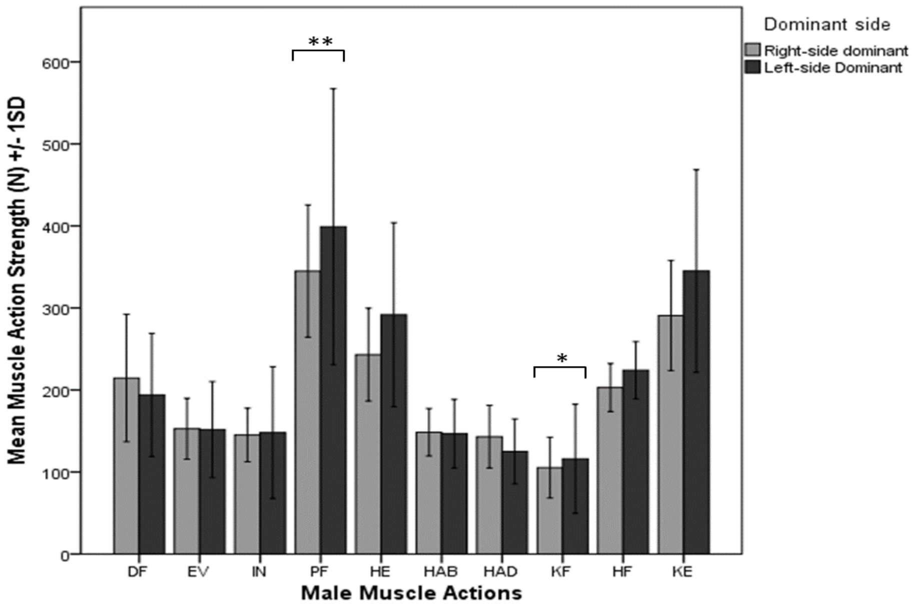


Figure 33 – Mean Muscle Action Strength in Males (Dominant vs Non-Dominant Side)

** Significant difference at the 0.01 level; * difference significant at the 0.05 level

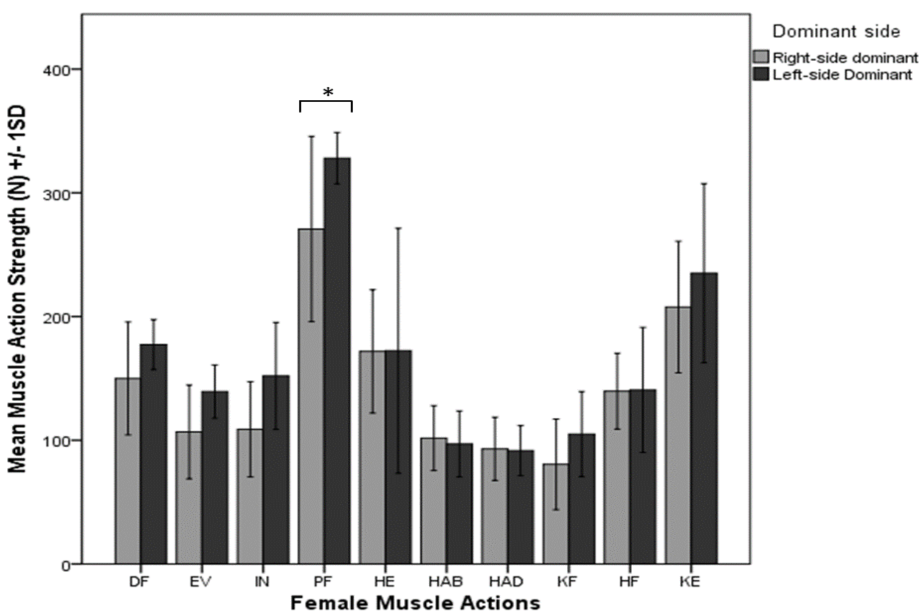


Figure 34 – Mean Muscle Action Strength in Females (Dominant vs Non-Dominant Side)

*Significant difference at the 0.05 level ***Key:*** *DF = Dorsiflexion; EV = Eversion; IN = Inversion; PF = Plantar flexion; HE = Hip Extension; HAB = Hip Abduction; HAD = Hip Adduction; KF = Knee Flexion; HF = Hip Flexion; KE = Knee Extension)*

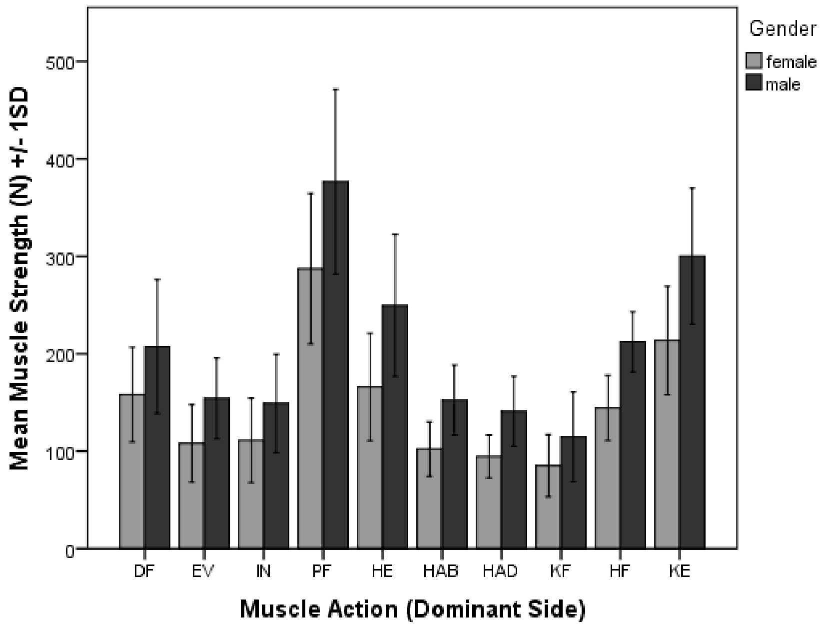


Figure 35 – Dominant Side Mean Muscle Action Strength by Gender

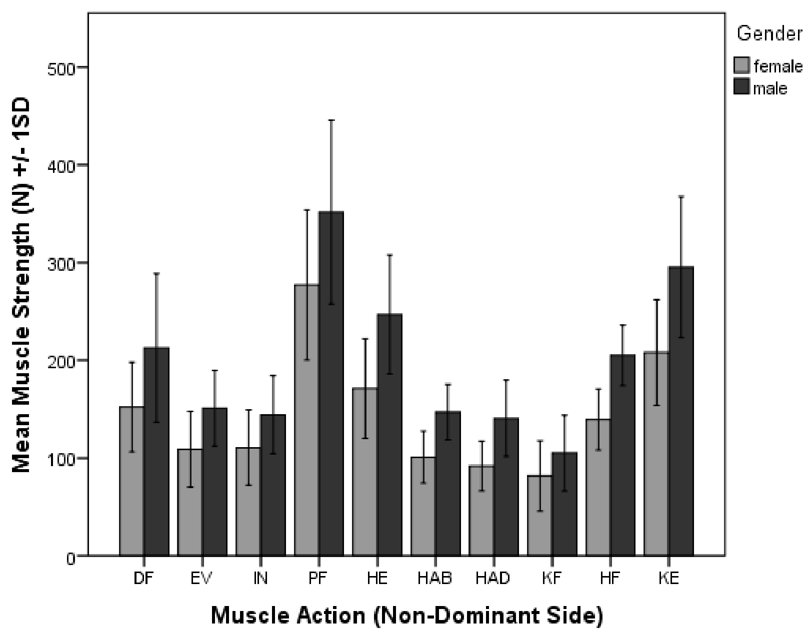


Figure 36 - Non-Dominant Side Mean Muscle Action Strength by Gender

*(**Key:** DF = Dorsiflexion; EV = Eversion; IN = Inversion; PF = Plantar flexion; HE = Hip Extension; HAB = Hip Abduction; HAD = Hip Adduction; KF = Knee Flexion; HF = Hip Flexion; KE = Knee Extension)*

Tables 22 & 23 present the PDT-Com scoring system which ranges from one (low force) through to six (high force). Each muscle action is divided into six equal sections by adding or subtracting multiples of half the standard deviation. Thus, a consistent range is created between each score from one to six for each muscle action. For example, if testing dominant side dorsiflexion, a female registering 152N would score four; or, if testing dominant side hip extension, a male registering 65N would score a two. Using these scores, the clinician can easily create a graphical representation that clearly highlights strength deficits for each patient (Figure 37).

Table 20 - Non-Dominant side muscle strength values in Newtons presented by muscle action and gender

Non-Dominant Muscle Action	Gender	Non-Dominant Side Muscle Strength Values (Newtons)					
		-1.5 *SD*	**-1 *SD***	**-.5 *SD***	**Mean**	**+.5 *SD***	**+1 *SD***
Dorsiflexion	F	83.5	106.4	129.3	152.2	175.0	197.9
	M	98.5	136.6	174.6	212.7	250.7	288.8
Eversion	F	51.1	70.4	89.7	109.0	128.3	147.7
	M	93.1	112.4	131.7	151.0	170.2	189.5
Inversion	F	52.8	72.1	91.3	110.6	129.9	149.1
	M	84.2	104.3	124.4	144.4	164.5	184.6
Plantar flexion	F	161.7	200.1	238.6	277.1	315.6	354.0
	M	210.5	257.6	304.6	351.6	398.7	445.7
Hip Extension	F	94.7	120.2	145.7	171.1	196.6	222.0
	M	155.8	186.2	216.6	247.0	277.4	307.8
Hip Abduction	F	61.0	74.3	87.6	100.9	114.2	127.5
	M	104.3	118.5	132.8	147.0	161.2	175.4
Hip Adduction	F	53.7	66.4	79.1	91.8	104.5	117.3
	M	82.2	101.7	121.2	140.7	160.2	179.7
Knee Flexion	F	27.8	45.7	63.7	81.7	99.7	117.7
	M	46.9	66.3	85.7	105.1	124.5	143.9
Hip Flexion	F	92.6	108.2	123.8	139.4	155.0	170.6
	M	158.7	174.2	189.7	205.2	220.6	236.1
Knee Extension	F	127.1	154.1	181.1	208.1	235.0	262.0
	M	187.0	223.1	259.2	295.3	331.4	367.6

Table 21 - Dominant side muscle strength values in Newtons presented by muscle action and gender

		Dominant Side Muscle Strength Values (Newtons)					
Non-Dominant Muscle Action	**Gender**	**-1.5 *SD***	**-1 *SD***	**-.5 *SD***	**Mean**	**+.5 *SD***	**+1 *SD***
Dorsiflexion	F	85.0	109.3	133.6	157.9	182.2	206.6
	M	104.2	138.5	172.9	207.3	241.7	276.0
Eversion	F	48.4	68.3	88.1	108.0	127.9	147.8
	M	92.2	112.9	133.5	154.2	174.8	195.5
Inversion	F	46.1	67.7	89.4	111.0	132.7	154.3
	M	73.5	98.7	124.0	149.2	174.4	199.7
Plantar flexion	F	171.4	210.0	248.7	287.3	325.9	364.6
	M	234.3	281.7	329.2	376.6	424.0	471.5
Hip Extension	F	83.0	110.6	138.2	165.8	193.4	221.0
	M	140.4	176.8	213.2	249.6	286.0	322.4
Hip Abduction	F	60.0	74.0	88.1	102.1	116.2	130.2
	M	98.6	116.5	134.5	152.4	170.4	188.4
Hip Adduction	F	61.5	72.5	83.6	94.6	105.6	116.6
	M	87.0	104.9	122.9	140.9	158.9	176.9
Knee Flexion	F	37.2	53.1	69.1	85.1	101.0	117.0
	M	45.7	68.7	91.7	114.8	137.8	160.8
Hip Flexion	F	93.9	110.7	127.5	144.3	161.1	177.9
	M	166.0	181.4	196.7	212.1	227.5	242.9
Knee Extension	F	130.0	157.9	185.8	213.6	241.5	269.4
	M	195.6	230.5	265.3	300.2	335.1	370.0

Table 22 - PDT-Com scoring system presented by muscle action, gender & non-dominant side

		PDT-Com Scoring System (Non-Dominant Side)											
Non-Dominant Muscle Action	**Gender**	**1**		**2**		**3**		**4**		**5**		**6**	
Dorsiflexion	F	0.0	95.0	95.1	117.9	118.0	140.7	140.8	163.6	163.7	186.5	186.6	∞
	M	0.0	117.5	117.6	155.6	155.7	193.6	193.7	231.7	231.8	269.8	269.9	∞
Eversion	F	0.0	60.7	60.8	80.0	80.1	99.4	99.5	118.7	118.8	138.0	138.1	∞
	M	0.0	102.8	102.9	122.1	122.2	141.3	141.4	160.6	160.7	179.9	180.0	∞
Inversion	F	0.0	62.4	62.5	81.7	81.8	101.0	101.1	120.2	120.3	139.5	139.6	∞
	M	0.0	94.3	94.4	114.3	114.4	134.4	134.5	154.5	154.6	174.5	174.6	∞
Plantar flexion	F	0.0	180.9	181.0	219.4	219.5	257.8	257.9	296.3	296.4	334.8	334.9	∞
	M	0.0	234.0	234.1	281.1	281.2	328.1	328.2	375.2	375.3	422.2	422.3	∞
Hip Extension	F	0.0	107.5	107.6	132.9	133.0	158.4	158.5	183.8	183.9	209.3	209.4	∞
	M	0.0	171.0	171.1	201.4	201.5	231.8	231.9	262.2	262.3	292.6	292.7	∞
Hip Abduction	F	0.0	67.6	67.7	81.0	81.1	94.3	94.4	107.6	107.7	120.9	121.0	∞
	M	0.0	111.4	111.5	125.6	125.7	139.9	140.0	154.1	154.2	168.3	168.4	∞
Hip Adduction	F	0.0	60.0	60.1	72.7	72.8	85.5	85.6	98.2	98.3	110.9	111.0	∞
	M	0.0	91.9	92.0	111.4	111.5	130.9	131.0	150.4	150.5	169.9	170.0	∞
Knee Flexion	F	0.0	36.8	36.9	54.7	54.8	72.7	72.8	90.7	90.8	108.7	108.8	∞
	M	0.0	56.6	56.7	76.0	76.1	95.4	95.5	114.8	114.9	134.2	134.3	∞
Hip Flexion	F	0.0	100.4	100.5	116.0	116.1	131.6	131.7	147.2	147.3	162.8	162.9	∞
	M	0.0	166.4	166.5	181.9	182.0	197.4	197.5	212.9	213.0	228.4	228.5	∞
Knee Extension	F	0.0	140.6	140.7	167.6	167.7	194.6	194.7	221.6	221.7	248.5	248.6	∞
	M	0.0	205.0	205.1	241.1	241.2	277.3	277.4	313.4	313.5	349.5	349.6	∞

Table 23 - PDT-Com scoring system presented by muscle action, gender & dominant side

		PDT-Com Scoring System (Dominant Side)											
Dominant Muscle Action	**Gender**	**1**		**2**		**3**		**4**		**5**		**6**	
Dorsiflexion	F	0.0	97.2	97.3	121.5	121.6	145.8	145.9	170.1	170.2	194.4	194.5	∞
	M	0.0	121.4	121.5	155.7	155.8	190.1	190.2	224.5	224.6	258.8	258.9	∞
Eversion	F	0.0	58.3	58.4	78.2	78.3	98.1	98.2	118.0	118.1	137.8	137.9	∞
	M	0.0	102.5	102.6	123.2	123.3	143.8	143.9	164.5	164.6	185.1	185.2	∞
Inversion	F	0.0	56.9	57.0	78.6	78.7	100.2	100.3	121.8	121.9	143.5	143.6	∞
	M	0.0	86.1	86.2	111.4	111.5	136.6	136.7	161.8	161.9	187.0	187.1	∞
Plantar flexion	F	0.0	190.7	190.8	229.3	229.4	268.0	268.1	306.6	306.7	345.3	345.4	∞
	M	0.0	258.0	258.1	305.5	305.6	352.9	353.0	400.3	400.4	447.7	447.8	∞
Hip Extension	F	0.0	96.8	96.9	124.4	124.5	152.0	152.1	179.6	179.7	207.2	207.3	∞
	M	0.0	158.6	158.7	195.0	195.1	231.4	231.5	267.8	267.9	304.2	304.3	∞
Hip Abduction	F	0.0	67.0	67.1	81.1	81.2	95.1	95.2	109.1	109.2	123.2	123.3	∞
	M	0.0	107.5	107.6	125.5	125.6	143.5	143.6	161.4	161.5	179.4	179.5	∞
Hip Adduction	F	0.0	67.0	67.1	78.1	78.2	89.1	89.2	100.1	100.2	111.1	111.2	∞
	M	0.0	96.0	96.1	113.9	114.0	131.9	132.0	149.9	150.0	167.9	168.0	∞
Knee Flexion	F	0.0	45.2	45.3	61.1	61.2	77.1	77.2	93.1	93.2	109.0	109.1	∞
	M	0.0	57.2	57.3	80.2	80.3	103.3	103.4	126.3	126.4	149.3	149.4	∞
Hip Flexion	F	0.0	102.3	102.4	119.1	119.2	135.9	136.0	152.7	152.8	169.5	169.6	∞
	M	0.0	173.7	173.8	189.0	189.1	204.4	204.5	219.8	219.9	235.2	235.3	∞
Knee Extension	F	0.0	143.9	144.0	171.8	171.9	199.7	199.8	227.6	227.7	255.4	255.5	∞
	M	0.0	213.0	213.1	247.9	248.0	282.8	282.9	317.7	317.8	352.6	352.7	∞

8.6 DISCUSSION

This study is the first to collect reference values of lower-extremity isometric muscle force using HHD for ten lower-extremity muscle actions in a small sample of 75 community-dwelling older adults. Few studies have evaluated or established muscle strength data beyond only a limited number of lower-extremity muscle actions. Previous authors using HHD values have either focussed their study on children aged between 4 and 16 years (456, 457), or on male football players (458). Moreover, they have only tested upper body muscle actions (460, 461), or six (258, 454, 457) or four (99), or three (307) muscle actions in older adults. This study does not set out to provide correlations between lower extremity muscle strength values and various independent variables (gender, age, height and weight) as these data are reported elsewhere (99, 258, 454).

This study found that muscle strength was higher in males when compared to females. This is because in healthy females' muscle mass accounts for approximately 30% of total body weight compared to 40-45% in males. Also, it has been reported that leg isometric muscle force output in females reaches on average approximately 70% of that in males (463).

Means and standard deviations of force for each muscle action in male and female community-dwelling older adults are presented in Tables 20 & 21. These data have been used to establish an objective scoring structure for the PDT-Com to assess the degree of a person's strength deficit compared to reference values. In below average scoring older adults the prescription and implementation of a targeted intervention towards above average values will help restore physical function and increase the likelihood of recovering from a trip or stumble.

The reliability of measurements obtained by HHD in this study is not surprising given the findings of previous research (99, 258, 346, 464). Internal consistency was established using the Cronbach's alpha value for the first measurement of each muscle action (α = 0.91). These results are consistent with other research findings (99, 222, 258) and strongly suggest the measurements support the construct of quantifying lower-extremity muscle strength. All intra-class coefficients were greater than 0.80 except plantar flexion (ICC = 0.44; 95% CI = -0.11 - 0.83) and knee extension (ICC = 0.56; 95% CI = -0.08 - 0.94) indicating only a moderate agreement (462). A possible explanation for these lower ICC scores in these muscle actions is the difference in muscle strength between the rater and subject. Previous research has shown that a prerequisite for reliable HHD measurements is adequate force generating capacity by the testers (454, 464, 465). Lu *et al* (466) reported that female raters have difficulties in measuring powerful muscle actions in male subjects because of their strength and size deficit compared to male raters. The incongruence between rater and subject evidences itself in this study in the plantarflexion and knee extension tests. These tests produced the highest HHD readings in male (568N & 456N respectively) and female (443N & 382N respectively) participants at the same time as having the lowest ICC scores of 0.44 and 0.56 respectively. Additionally, the lack of stabilisation of the HHD may have decreased the force readings unless belt stabilisation (467), strap modification (467) or frame-stabilisation (468) was used.

A summary of several papers that purport to provide normative values for limb muscle actions are presented in Table 24. As expected, the muscles of the right side were stronger than compared to the left side (92% were right-side dominant with 8% being left-side dominant). Although ankle planter flexion, hip flexion and hip extension strength were significantly different (in terms of statistical significance) between dominant and non-dominant sides (ankle plantar flexion, p <0.001; hip flexion, p < 0.003; hip extension, p <0.009), the differences between each appear to be too small to be clinically relevant. This observation are consistent with Stoll *et al* (463) who, when measuring muscle force using an isokinetic dynamometer, found a statistically significant difference in force outputs between sides and also reported these differences to be too small to be of clinical relevance. Additionally, Andrews *et al* (258) found no statistically significant differences in muscle force outputs between any of the five lower-extremity muscle actions tested. That said, and although separate values for dominant and non-dominant sides appear clinically irrelevant, a decision was made to include them as part of the PDT-Com scoring system for those clinicians who might wish to use them.

The muscle action force measurements in this study differ from that of others. For example, Andrews *et al* (258) studied asymptomatic older adults to determine normative values for isometric force production using HHD. They examined eight upper-extremity and five lower-extremity muscle actions. All measurements were taken with the subjects in the supine position except for knee flexion and extension, which were measured in the sitting position. Our measurements varied between lying supine (hip flexion), side-lying (hip abduction and adduction, lying prone (hip extension), sitting with knee extended (all ankle force measurements), standing prone position (hip extension), and sitting in a chair (knee extension). Andrews *et al* reported higher force outputs for all lower-extremity muscle actions, whereas force outputs for hip flexion were lower than those obtained in this study. This is likely a result of a length-tension phenomenon where the optimum length of the muscle to produce force is exceeded (77, 84). In our study, subjects are tested with the hip reduced to 45 degrees of flexion because of this phenomenon. Bohannon (213) also examined subjects in the supine position, but used a wide range of ages and the subjects were neurologically impaired.

During preliminary work for the design of the PDT-Com there was a repeated struggle to overcome the short lever arm of the ankle joint when measuring plantar flexion. The seated positions chosen for plantar flexion and knee extension in this study may have placed too much of an advantage with the subject. In a study by Kelln *et al* (465) the authors stated clearly that the emphasis was to minimize the ability of the subject to overpower the tester and as a result produce repeated reliable measures of strength. The design of the PDT-Com overemphasised mechanical advantage and despite several attempts to modify subject and rater positions for plantar flexion, the author was unable to devise a suitable test that produced reliable measurement. Thus, it may be necessary to omit measurement of plantar flexion force from the PDT-Com test battery, per precedent set by other studies (454, 455, 465).

Table 24 - Summary of studies reporting reference/normative values obtained by hand-held dynamometer

	Subjects					Dynamometer	
Reference	***n***	**Age Range**	**Gender**	**Actions Tested**	**Test Type**	**HHD Make**	**Max Load (N)***
Macfarlane (456)	154	6-8	M/F	Lower Body	Make Test	Microfet II	667
Beenakker (457)	270	4-16	M/F	Upper & Lower Body	Break Test	CT 3001	999
Andrews (258)	156	50-79	M/F	Upper & Lower Body	Make Test	Chatillon CSD400c	512
Hanna (458)	120	15-45	M	Lower Body	Make Test	Industrial Research Ltd	800
Turner (459)	172	11-60	M/F	Upper Body	Make Test	Basline Hydraulic Push-Pull	Not Reported
Bohannon (99)	131	20-79	M/F	Upper & Lower Body	Make Test	Accuforce II	650
Van Harlinger (461)	180	20-64	M/F	Upper Body	Break Test	Nicholas Manual Muscle Tester	Not Reported
Riemann (460)	181	Not Reported	M/F	Upper Body	Not Reported	Not Reported	Not Reported
van der Ploeg (454)	100	20-60	M/F	Lower & Upper Body	Make Test	Wika Pressure Gauge	300†

Abbreviations: M = Male; F = Female; HHD = Hand-held Dynamometer; *n* = Subject Number; N = Newtons
* Converted to Newtons based on primary units reported; † = Limited to 250 N in study

8.6.1 Strengths of the Study

One of the strengths of this study lies in its ability to combine both intra- and inter-rater reliability testing. As a result, there can be confidence that the majority of error observed were due to differences between raters. This study benefitted from a robust and rigorous standardised measurement procedure that had been reviewed and revised to maximise consistency. During pilot work and subsequent clinical practice by each rater, there was no additional training or familiarisation with the PDT-Com protocol. Additional training was deemed unrealistic and impractical. In order to avoid any potential over-reliance on a system of training that was not deliverable, the decision was taken to avoid the introduction of training into the protocol.

This study is also strengthened by its inclusion of ten lower-extremity muscle actions. Other research using HHD has only tested a few muscle actions in the lower-extremity. For example, the Physiological Profile Assessment (PPA) by Lord *et al* (307) objectively measures three muscle groups on the dominant side only. Typically, six or fewer muscle actions have been used in studies establishing reference or normative strength values when obtained by HHD (99, 258, 454, 456-458, 469). Stoll and colleagues (463) did measure 10 lower-extremity muscle actions in their study of normative values but these data were obtained using a pull gauge.

Another advantage of the PDT-Com manual muscle testing procedure is that it can be completed by a trained assessor in approximately 20-30 minutes. In contrast, the PPA by Lord *et al* (307) is considerably more complex and time consuming (45 minutes). A less complex short-form PPA takes approximately 10-15 minutes to administer is also available, but it is of limited informational value to the clinician.

8.6.2 Limitations of the study

This study has limitations which should be considered. Firstly, the sample size was sub-optimal with only 75 subjects recruited instead of the desired 100. The shortage of male participants is difficult to explain but may be in part due to the sampling frame. Volunteers were sought from local yoga and Tai Chi groups which have a high female to male membership ratio. Ideally, a sample size of 300 would have enabled stratification by age groups as well as by gender. There was also a lack of left-side dominant subjects to compare any left/right-side dominance patterns.

Secondly, although the standardisation is a strength of this study, the limited availability of training may compromise raters using HHD and PDT-Com protocol to obtain accurate and reliable data. Considering the several low ICC values and high SEM values recorded it may be necessary to expose the raters to more training and practice to obtain reliable measurements. Thirdly, this study may reflect a selection bias: its subjects were already participating in physical activity (walking, gardening etc.), exercise (running, badminton and cycling), and group exercise classes (yoga, Tai Chi and Pilates). In addition, subjects' mean age was only 67 and 65 years for men and women respectively.

Finally, it is impossible to randomly sample from a population because there is no list (sample frame) of eligible people to sample from, other than the population census (470). Additionally, these data can only be applied to the small sample tested and the reliability of measurements may be compromised if the same test battery is used on an older and frailer population. Furthermore, younger and potentially more athletic populations may produce greater force than could be achieved by the tester and thereby bring the accuracy of the measurements into question. However, if the main outcome of testing is to establish absolute maximal force outputs in younger (or athletic) populations then the use of fixed isokinetic dynamometry or traditional one-repetition maximum strength protocols may be advisable in preference to HHD.

8.6.3 Clinical Implications

The reference values and ranges provided in this study could potentially be used in a clinical setting to establish which lower-extremity muscle groups have a strength deficit compared both to themselves and to healthy community-dwelling older adults. The clinician can use this data on individual muscle groups or as part of a test battery to establish a general picture of a person's lower-extremity strength. Figure 37 shows a computer-generated output of a pre- and post-exercise intervention PDT-Com assessment test.

PDT Composite Scores (pre-intervention)

Hip	Raw	%
Left	23	63.9
Right	20	55.6
Flexion	11	45.8
Extension	14	58.3
Total	43	59.7
Lower-limb		
Left	16	66.7
Right	6	25.0
Total	22	45.8

	Raw	%
Total Left	39	65.0
Total Right	26	43.3
Movement	12	66.7
Flexibility	13	72.2
Total composite	90	57.7

PDT Composite Scores (post-intervention)

Hip	Raw	%
Left	36	100.0
Right	36	100.0
Flexion	24	100.0
Extension	24	100.0
Total	72	100.0
Lower-limb		
Left	18	75.0
Right	18	75.0
Total	36	75.0

	Raw	%
Total Left	54	90.0
Total Right	54	90.0
Movement	17	94.4
Flexibility	18	100.0
Total composite	143	91.7

Figure 37 - Pre-intervention (left) & Post intervention (right) PDT-Com Scoring Graphs

8.6.4 Research Implications

In answer to the limitations established so far, a study applying the PDT-Com assessment protocol to a larger and more diverse sample of older adults could be used to create a database of reference values. This would allow further investigation stratified by age category (60-65; 66-70; 71-75 etc.), height, weight and activity levels. These data may be useful for further studies investigating who is likely to fall, and useful in the development and prescription of individually prescribed exercise intervention programmes targeting the lower-extremity. This information has the potential to be used to assess and monitor healthy community-dwelling older adults for muscle strength deficits, and in conjunction with further research on a larger population, may be useful in the identification of fall risk factors and the development of an individualised exercise intervention programme.

8.7 CHAPTER SUMMARY

This chapter has obtained lower-extremity muscle action force reference values in healthy community-dwelling older adults. This data can be used to develop an accurate and reliable scoring system which can be used to test the absolute and relative reliability of the PDT-Com assessment tool.

9 INTRA- AND INTER-RATER RELIABILITY OF THE NEWLY DEVELOPED PDT-COM ASSESSMENT IN COMMUNITY-DWELLING ADULTS AGED OVER 60

9.1 OVERVIEW

In the preceding eight chapters the challenges associated with falling in older adults have been discussed. The need for a physical assessment to direct an intervention to address modifiable physiological risk factors has been highlighted as the focus of this thesis. Having developed an assessment tool to identify modifiable physical risk factors in community-dwelling adults aged over 60, the next phase of work was to determine the validity and reliability of this tool when used in a sample from within this broader population.

This chapter describes two studies: the first explores the inter-rater reliability of the movement competency scoring section of the PDT-Com and the second explores the inter-rater reliability of the PDT-Com manual muscle testing protocol using hand-held dynamometry (HHD) in the measurement of lower-extremity muscle strength (Appendix H). Such an assessment tool needs to be valid and reliable to be useful for health professionals. Often there is discrepancy between the numbers in what we are measuring and the actual true value. This discrepancy is known as measurement error. One way to ensure measurement error is kept to a minimum is to determine whether the properties of that measure give us confidence that the values or values obtained are correct. The first property is validity, which is whether an instrument or tool measures what it sets out to measure. The second property is reliability, which is whether an instrument or tool can be interpreted consistently across different situations (471). A discussion of the theoretical aspects of validity and reliability was already discussed in Chapter 5.

9.1.1 Reliability

In brief, reliability, is concerned with consistency, repeatability and agreement of a measure (215, 472). Regardless of what is being measured, the results of any given test or tool should be the same whether the construct is tested by the same person at different times, or by different people at the same time. When assessing the ability of a measurement or test to be clinically helpful, it is important for the interpretation to not be a product of guesswork (472). For a measure to be clinically useful, it must be consistently accurate. In other words, the measure needs to be valid and reliable.

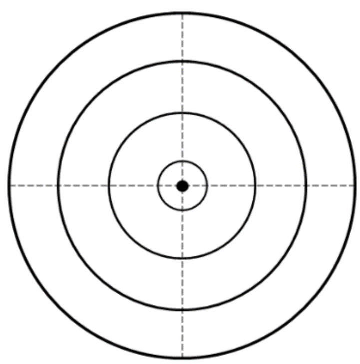


Figure 38 - Target analogy for accuracy (validity) and precision (reliability)

The meaning of validity and reliability and the relationship between them is best shown using a diagram. The target is what we are measuring (Figure 38) and the bull's eye represents a perfect measurement. Thus, reliability can be thought of as imprecision, and validity can be thought of as inaccuracy. The closer the points are to the centre the more accurate (valid), and the closer the points are to each other the more precise (reliable) the measurement is. However, a test or measurement cannot be considered valid if it is not reliable. In other words, if a test cannot give consistent measurements (i.e. if successive trials yield different results) then the test cannot be trusted (215, 447, 451, 472).

With reference to Figure 39a it is possible, then, to hit the centre of the target purely by chance with little precision meaning there is accuracy but no precision (poor reliability about where the shots land on the target). In C, the dots are neither close to the centre or closely grouped demonstrating both poor accuracy and precision. The dots in D are closely grouped but are not close to the centre indicating there is precision but not accuracy. In B, there is both accuracy and precision.

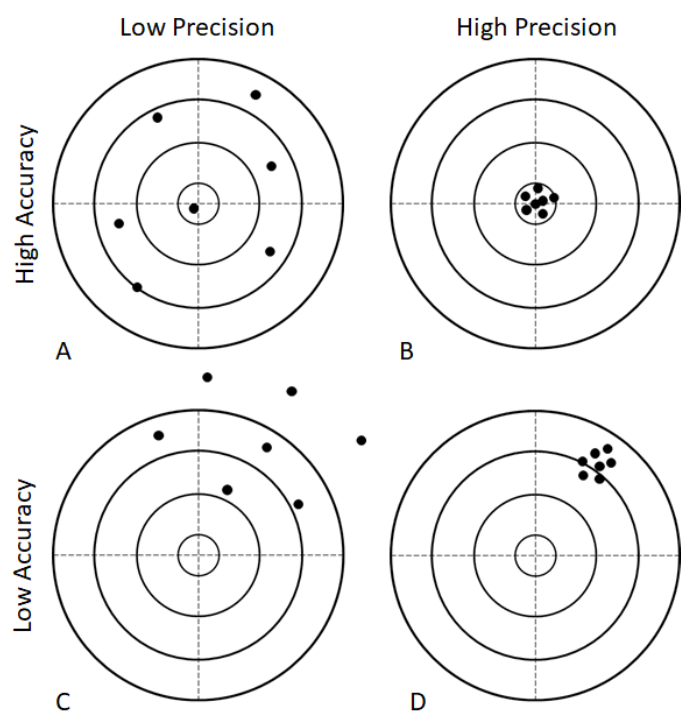


Figure 39 - Target Matrix showing the relationship between accuracy and precision

The lack of precision in A and C can be down to chance, meaning that the bull's eye shot was 'lucky'. The groupings in targets B and D are unlikely to be due to chance. In the context of measuring lower-extremity muscle strength, reliability is the degree to which the measurement is free from measurement error. Considerable research has addressed the reliability of measurements obtained using a HHD in younger adults, and symptomatic or impaired older adults, but few in healthy older populations.

This research addresses internal consistency (213, 219, 258), test-retest reliability (346, 473) and intra- and inter-rater reliability (379, 473, 474). Measurement of internal consistency is used when several items contribute to a composite score that represents a given construct, for example, lower-extremity muscle strength. Internal consistency itself is not an adequate measure of reliability. However, it does contribute to the clinical worthiness of measurements and is defined as the average correlation between measures (388). In other words, it measures whether several items that propose to measure the same general construct produce similar scores.

Test-retest reliability is primarily concerned with the consistency of repeated measurements on the same ‘thing’ multiple times, either at different time-points or using different raters/tools) (215). For these measurements to be considered stable over time, comparable results are required to be collected by the rater at different time-points. Thus, test-retest methods involving little to no time interval between measurements (also referred to as the same-day test-retest method) give an indication of general reliability of the tool (215). With respect to HHD, few factors are likely to influence test results in a short period of time and close to identical results are likely. In this instance, any observed disparity between results suggests inconsistency in the measuring capacity of the tool itself, the influence of the rater(s) and/or any learning effects of the subjects must be considered.

Two forms of reliability applicable to the tester are Intra-rater (or sometimes referred to as ‘within-rater’) and inter-rater (referred to as ‘between’) reliability analysis. Intra-rater reliability examines whether consistent results are achieved by the same rater, and is achieved by taking two or more consecutive measurements. On the other hand, inter-rater reliability (or ‘objectivity’) represents how well a measuring tool offers consistent measurements when used by different raters on the same thing (215). The degree of reliability can easily be established by two or more raters gathering data at the same time.

9.2 BACKGROUND

The assessment of lower-extremity muscle strength and human physical function (in the form of everyday movements such as the squat), are useful outcome measures both in research and clinical settings to identify physical deficits and to inform prescription of intervention strategies (101). In the context of measuring lower-extremity muscle strength, reliability is the degree to which the measurement is free from measurement error (450). Considerable research has addressed the reliability of measurements obtained using an HHD in younger adults, and symptomatic or impaired older adults, yet little research has been conducted in a healthy older adult population. This study therefore addresses internal consistency (147, 189, 215), test-retest reliability (202, 216) and intra- and inter-rater reliability (216-218) of HHD in a sample of healthy adults aged over 60 years.

The Performance Deficit Test for community-dwelling adults (PDT-Com) is designed to measure domains of physical function. Specifically, it is designed to simultaneously measure absolute and relative lower-extremity muscle action strength and asymmetries, dynamic stability, dynamic range of movement and movement competency (movement ability and quality). These measurements have the potential to provide health professionals with valuable clinical information about muscle strength deficits and asymmetries that may relate and contribute to functional limitations (12, 24, 42, 43, 71, 307-309). Health professionals will often take multiple measurements when using HHD testing and thus, the PDT-Com could be used by different health professionals/raters on the same day. For intrinsic risk factors associated with falling, such as lower-extremity muscle strength deficits, gait and balance problems and movement impairments, it is necessary to see how these factors vary over time.

9.3 OBJECTIVE

The objective of the two studies was to determine the inter-rater reliability of the PDT-Com assessment protocol for measuring muscle strength and movement impairments in a sample of adults aged 60 years and over.

Research Question: How reliable is the PDT-Com assessment procedure in the measurement of lower-extremity muscle strength and the identification of movement dysfunctions in the squat, lunge and single leg squat when used by independent healthcare professionals?

9.4 STUDY ONE - MOVEMENT COMPETENCY ASSESSMENT

9.4.1 Design

Study one aimed to investigate the inter-rater reliability of the movement competency scoring section of the PDT-Com. Inter-rater reliability was determined using two trained health care professionals (raters) in one session observing video recordings of different subjects performing each of the movement competency tests. Raters scored subjects independently and had unlimited access to the video recordings.

9.4.2 Subjects

Healthy community-dwelling older adults (n = 30; men = 15; women = 15; age = over 60 years) were selected from a convenience sample of fee paying private clinic injury rehabilitation clients (Table 25). Healthy was defined as an individual living independently in the community who was not receiving any current treatment for a musculoskeletal condition. Subjects were not eligible if they resided in nursing homes or if they self-reported any of the following:

- Parkinson's disease
- multiple sclerosis
- marked cognitive impairment
- heart disease
- suffering from systemic disease such as hypotension
- diagnosed with osteoporosis
- spinal trauma
- acute rheumatoid arthritis
- within 12 months of ankle, knee or hip joint surgery

Subjects were asked to avoid moderate to intense exercise within 24 hours prior to the test, but light activities were permitted. The procedure of the study was explained to each participant on arrival at the testing facility.

Table 25 - Characteristics of Study Subjects (*n* = 30)

	Age (years.)		**Height (cm)**		**Weight (kg)**	
Gender	**Mean**	***SD***	**Mean**	***SD***	**Mean**	***SD***
F (*n* = 15)	65.0	6.0	163.5	6.5	63.7	8.7
M (*n* = 15)	67.0	7.0	177.8	5.3	82.7	8.6

9.4.3 Raters

Two qualified health professionals assessed and scored movement competency using the PDT-Com procedure. The respective backgrounds were as follows:

- Rater 1: 31-year old female Chartered physiotherapist (Height 160 cm; Weight 58 kg) with seven years of private clinic experience (>3 years using hand-held dynamometry);
- Rater 2: 43-year old male strength & conditioning coach (Height 180 cm; Weight 90 kg) with 10 years private clinic experience (>3 years using hand-held dynamometry).

Both raters received a training manual detailing how to score each subject, including four hours of additional training using video footage of a convenience sample of healthy older adults.

9.4.4 Sample Size Calculation

The sample size for this reliability study was based on a method developed by Walter *et al (*1998). This method was developed to calculate the required number of subjects in a reliability study, where reliability is measured using the ICC (475). In order to demonstrate a level of reliability deemed substantial (462), the ICC (ICC) chosen was 0.80. Therefore:

H_0: ICC is less than or equal to .60

H_1: ICC is greater than .80

It was calculated that 30 participants would give 90% power to detect a difference between an ICC of .60 and .80 (475).

9.4.5 Procedures

Full details of the PDT-Com movement competency assessment procedures can be found in Appendix H. Subjects were recorded in High Definition video using a web-cam (LifeCam Cinema H5D-00003, Microsoft Hardware, Berks, UK). The PDT-Com movement assessment considers three whole-body movements to determine the level of functionality amongst participants. These tests include the squat, the lunge and the single leg squat. Subjects were required to perform each exercise three times in both sagittal (anterior) and frontal (lateral) plane views while being videotaped. In addition, the squat exercise included a posterior view. Subjects performed each movement without footwear. A rest period of ten seconds was given between each plane view to reduce the effects of fatigue. Raters scored each subject on a one to six ordinal scale as set out in the PDT-Com scoring criteria (see Appendix H).

9.4.6 Statistical Analysis

All descriptive analyses were conducted using SPSS (version 22). Data analysis included descriptive statistics of sample characteristics. Before statistical analysis, data were checked using double entry by the author, screening for erroneous values and missing items (447). The inter-rater reliability for the PDT-Com composite movement score was established using ICC ($ICC_{2,1}$) (476). To determine the overall percentage of agreement between raters, a weighted (quadratic) kappa Coefficient statistic was used due to the categorical nature of the data (449).

The kappa test is a measure of true agreement and indicates the proportion of agreement beyond that expected by chance for categorical data (477). The calculation is based on the difference between how much agreement is actually present ('observed' agreement) compared to how much agreement would be expected to be present by chance ('expected' agreement) (472). It takes the following form:

K = observed agreement – chance agreement

In terms of formula, this is expressed as:

$$\mathrm{K} = \frac{Po - Pc}{1 - Pc}$$

where *Po* is the proportion of observed agreements and *Pc* is the proportion of agreements expected by chance (477). While Cohen's kappa for continuous data is most frequently used, the concept of kappa testing has also extended to nominal and ordinal outcomes (Weighted Kappa) (478).

The basic kappa principle can be used beyond binary responses (disease present/absent) to nominal and ordinal outcomes. This is especially useful when there are more than two response options giving increased rating precision, but differentiation of absolute agreement and disagreement is still important. Therefore, weighted Kappa (K_w) is used to attach greater emphasis to large differences between raters and penalises disagreements in terms of their seriousness, whereas unweighted Kappa treats all disagreements equally (472, 477). Weighted kappa takes the following form:

$$k_w = \sum wf_o \; - \mathrm{w}f_c$$

$$n - \sum w\, f_c$$

With $\sum wf_0$ being the sum of the weighted observed frequencies and wf_c being the sum of the weighted frequencies predicted by chance. In the case of the movement section of the PDT-Com assessment a subject being scored as six by one rater and four by another should result in a lower IRR estimate than when a subject is scored six by one rater and five by another (478).

The most commonly reported weights are linear and quadratic weights, originally introduced by Cohen (449). Linear weighting assumes that the relative differences between any two scoring categories are the same and penalises disagreements between raters equally. The weight can be calculated as follows:

$$Weight_i = \frac{i}{\mathrm{k} - 1}$$

where i is the number of categories the raters disagree by, and k the number of categories in the outcome variable. However, the differences between scores in the PDT-Com are not linear and therefore a quadratic weighting formula was applied. Calculation of quadratic weights is similar to linear weights, but the differences are squared, resulting in greater proportional penalties for greater disagreements between raters. It can be calculated as follows:

$$Weight_i = \frac{i^2}{(k-1)^2}$$

or expressed as:

$$1 - \frac{distance\ between\ ratings^2}{\mathrm{M}aximal\ distance^2}$$

The quadratic weights for agreement were as follows: no difference equalling 1.0, disagreement by 1 category equalling .89, disagreement by 2 categories 0.56 and disagreement by 3 categories equalling .33. The frequency of each score combination in the contingency table being multiplied by its respective quadratic weight to indicate a greater significant effect of a larger agreement (477). Landis & Koch (462) describe the strength of agreement between Kappa in Table 26. Similar formulations exist in the research literature (446, 447, 462, 477, 479) but with slightly different descriptors. Similar formulations exist in the research literature (446, 447, 462, 477, 479) but with slightly different descriptors.

Table 26 **-** Kappa Agreement. Taken from Landis & Koch (462)

Value of Kappa	Strength of Agreement	% Agreement
< 0.20	Slight	4-15
0.21 - 0.40	Fair	16-35
0.41 - 0.60	Moderate	36-63
0.61 - 0.80	Substantial	64-81
0.81 - 1.00	Almost Perfect	82-100

9.4.7 Ethical Approval

Full ethical approval by the University of Warwick's Biomedical and Scientific Research Ethics Committee was obtained (REGO-2014-708 – see Appendix C). Written informed consent was obtained from all participants (Appendix D).

9.4.8 Results

The results from the inter-rater reliability analysis for the sample of 30 participants are presented in Table 27. Cohen's Kappa (K_w) *was* computed for both raters for each movement (squat, lunge and single-leg squat), which indicated substantial agreement for all three movements (p <0.001). The high ICC suggests that a minimal amount of measurement error was introduced by the independent raters.

Table 27 - Weighted Kappa values comparing Rater 1 and Rater 2 (n = 30)

Movement Test	**Kappa**	**SE**	**CI (95%)**	**Level of Agreement****
Squat	0.92	0.062	0.80 - 1.04	Almost Perfect
Lunge	0.86	0.078	0.71 - 1.01	Almost Perfect
SLSQ*	0.85	0.073	0.71 - 0.99	Almost Perfect

*SLSQ = Single Leg Squat; ** Landis & Koch (462)

9.5 STUDY TWO - LOWER-EXTREMITY MUSCLE STRENGTH TESTING

9.5.1 Design

Study Two was a single-group repeated measures design that investigated inter-rater reliability (IRR) of the PDT-Com manual muscle testing protocol (using HHD) in the measurement of lower-extremity muscle strength. This was conducted in a separate community-based sample of participants from study one and tested inter-rater reliability between three trained raters. These raters used a calibrated HHD to independently measure subjects' lower-extremity muscle action strength. The standardised scoring and measuring criteria, as described in Appendix P, was used in this study.

9.5.2 Subjects

A convenience sample of healthy, independently living adults (*n* = 30; women = 19; men = 11; Age >60 years) from the local community were invited to participate in this study (Table 28). Healthy was defined as an individual living independently in the community who was not receiving any current treatment for a musculoskeletal condition. Participants were recruited from voluntary organisations, independent living facilities and by word of mouth from the areas of Warwickshire and Northamptonshire.

Table 28 - Characteristics of study two participants (*n* = 30)

	Age (years)		**Height (cm)**		**Weight (kg)**	
Gender	**Mean**	***SD***	**Mean**	***SD***	**Mean**	***SD***
F (*n* = 19)	64.3	4.6	162.8	8.9	60.0	6.1
M (*n* = 11)	65.2	5.5	177.0	5.5	77.8	14.2

Participants were excluded as per study one exclusion criteria for comorbidity. Similarly to study one, participants were asked to avoid moderate to intense exercise within 24 hours prior to the test, but light activities were permitted. The procedure of the study was explained to each participant on arrival at the testing facility.

9.5.3 Raters

In this Study, the same two raters for study one were used in addition to a third qualified health professional. Details of the third professional were as follows: Rater 3: 28-year old female Graduate Sports Therapist (Height 158 cm; Weight 57 kg) with 4 years private clinic experience. All raters received a training manual outlining how to conduct the HHD testing for each muscle action. Raters also attended four hours of HHD training led by the principal investigator.

9.5.4 Sample Size Calculation

Sample size calculations for study two were determined using the same principles described in study one. Therefore, 30 participants were considered sufficient to provide 90% power to detect a difference between an ICC of 0.60 and 0.80 (475).

9.5.5 Procedures

Full details of the PDT-Com lower-extremity muscle strength assessment procedures can be found in Appendix H. Details of the dynamometer placement, limb positions and subject stabilisation are provided in Table 18 (Chapter 7, p146). For all tests, the calibrated HHD (Manual Muscle Tester LIC.01163, Lafayette Instrument Company, Loughborough, Leicestershire UK) was programmed to measure the peak force in kilogrammes during five seconds (s) of voluntary maximal muscle contraction. The HHD indicated the start and finish points of the 5s contraction duration by an audible beep. Rater and participant positioning were the same as detailed in Table

18. The subjects were asked to wear loose fitting clothes and to remove their footwear. If required, clothing was adjusted to reveal both ankle joints. Subjects were instructed to exert maximum force against the applicator, and the rater applied a countering force to oppose the subject's force. The rater then removed the HHD from the limb and force was recorded. There was approximately 5s between contractions and a 20s rest period was given between each muscle group, and approximately 10 minutes rest between raters. Rest periods were timed using a standard sports stop-watch (Fastime DB3, Astopwatch Ltd., Leics, UK). Intra-session reliability was evaluated by one rater using two trials for each muscle group on 10 subjects. The inter-rater reliability was tested using all three raters on all participants measured approximately 10 minutes apart. The order that the raters tested participants was rotated and the muscle actions were tested in no predetermined order.

9.5.6 Statistical Analysis

All statistical analyses were calculated using SPSS (version 21). Descriptive analyses were undertaken on sample characteristics. The use of reliability statistics discussed below rely on normal distribution of continuous data i.e. are parametric. Test-retest reliability of the repeated measurements of each muscle on each subject's dominant side were established by examining the differences in HHD forces from 10 subjects (female n = 5; male n = 5) using analysis of variance (ANOVA), calculating reliability coefficients ($ICC_{3,1}$) and a 95% confidence interval. The degree of inter-rater reliability was established by analysing the scores using intra-class correlation techniques. This equated to the ratio of variance between subjects to error variance and can be defined as:

$$p = \sigma_s^2 / (\sigma_s^2 + \sigma_e^2)$$

where σ_s^2 and σ_e^2 are the among-subjects and within-subjects components of variance, respectively (448). There are different versions of this depending on the assumptions that are made. In this study the observers were a sample of all possible and were treated as a random factor. Therefore, ICC $_{2,1}$ was selected because there were more than two raters who were considered to be a sample of all possible raters (476).

Absolute reliability was established using the following statistical procedure. The Standard Error of Measurement (SEM) was calculated using the ICC coefficient and standard deviation. This enabled a 95% confidence interval around the mean to be calculated. SEM was calculated using the following formula (where *s* is the standard deviation):

$$\mathrm{s}\sqrt{1 - ICC}$$

The SEM% was also calculated as the SEM divided by the mean force for all measurements from raters 1, 2 and 3 and multiplied by 100% to give a percentage value. The SEM% is independent of other measures and represents the limit for the smallest change that indicates a real change in a group of subjects. The degree of inter-rater reliability for the Composite Movement Score was established by analysing the scores using $ICC_{2,\,1}$.

9.5.7 Results

A total of 30 participants were recruited to the study and their characteristics are presented in Table 28. A muscle force value was reported for each of the 9 muscle actions separately for men and women, presented in Table 29. Men had statistically significantly greater muscle force than women (P = <.001) in most of the muscle actions except for knee extension (p = <.05), ankle inversion, ankle eversion and ankle dorsiflexion (p = >.05).

A summary of statistics describing the reliability of the HHD measurements is presented in Table 30. Test-retest reliability coefficients were similar for men ($ICC_{3,1}$ = .91 - .98) and women ($ICC_{3,1}$ = .87 - .97). Therefore, the test-retest reliability coefficients, SEMs and SEM% for each muscle group were reported for combined data from both gender samples. Test-retest reliability was between 0.91 and 0.98 (CI 95% = .71 - .99) indicating almost perfect agreement (462). Confidence intervals for all ICCs were between 0.80 and 0.99, except for knee flexion (CI 95% = .71 - .97) and hip abduction (CI 95% = .79 - .98).

The intra-rater reliability of HHD measures for each muscle action is presented in Table 31. The Intra-rater ICC values ranged from .91 to .99. Mean ICC values for Rater 1, 2 and 3 were .98, .97 and .98 respectively indicating almost perfect agreement with themselves (462). The SEM values across all three raters ranged from 5.7N (ankle eversion) to 26.3N (knee extension).

Table 29 - Male and female strength values (Mean ± *SD*) of each muscle action

	Men (n = 14)		Women (n = 16)	
Muscle Action	**Mean (Newtons)**	***SD***	**Mean (Newtons)**	***SD***
Hip Extension	223.7**	63.6	172.6	39.4
Knee Flexion	120.7**	33.3	85.7	16.4
Knee Extension	297.4*	94.7	249.6	65.0
Hip Abduction	164.5**	43.5	107.7	38.8
Hip Adduction	136.1**	29.6	95.3	16.3
Hip Flexion	186.9**	47.9	140.9	24.1
Ankle Inversion	138.1	44.2	127.0	38.3
Ankle Eversion	145.4	47.1	125.6	36.2
Ankle Dorsiflexion	201.7	63.1	188.8	52.0

* $P<0.05$ (gender difference); ** $P < .001$ (gender difference)

Table 30 - Test-Retest Reliability of HHD Measurements of Force Obtained During a Single Session by One Rater (*n* = 10)

		Mean Force (N)				
Muscle Action	**Side**	**Test 1**	**Test 2**	***F***	***P***	**ICC (CI 95%)**
Hip Extension	Dominant	191.7	190.9	*87.02*	*.001*	.98 (.92 - .99)
Knee Flexion	Dominant	91.6	88.7	*24.02*	*.001*	.92 (.72 - .98)
Knee Extension	Dominant	251.5	246.0	*56.08*	*.001*	.96 (.87 - .99)
Hip Abduction	Dominant	141.8	140.3	*35.13*	*.001*	.94 (.79 - .98)
Hip Adduction	Dominant	117.5	121.1	*33.50*	*.001*	.94 (.79 - .98)
Hip Flexion	Dominant	163.8	163.5	*45.65*	*.001*	.96 (.85 - .99)
Ankle Inversion	Dominant	133.2	131.5	*45.27*	*.001*	.96 (.85 - .99)
Ankle Eversion	Dominant	132.2	134.2	*82.50*	*.001*	.98 (.91 - .99)
Ankle Dorsiflexion	Dominant	191.3	194.7	*123.56*	*.001*	.98 (.91 - .99)

N = Newtons; ICC = Inter-class Correlation Coefficient

Table 31 **-** Intra-rater reliability ICC and SEM values obtained in one session for each rater for each muscle action

	Rater 1		Rater 2		Rater 3	
Muscle Action	**ICC (95% CI)**	***SEM**	**ICC (95% CI)**	***SEM**	**ICC (95% CI)**	***SEM**
Hip Extension	.98	17.5	.94	16.6	.98	16.8
Knee Flexion	.98	9.5	.99	6.1	.96	7.8
Knee Extension	.97	26.3	.97	21.8	.98	18.8
Hip Abduction	.98	11.3	.95	15.6	.98	11.8
Hip Adduction	.99	8.9	.91	21.2	.99	6.5
Hip Flexion	.99	5.8	.98	10.9	.98	11.9
Ankle Inversion	.97	9.7	.97	9.1	.93	12.9
Ankle Eversion	.98	8.1	.97	10.3	.99	5.7
Ankle Dorsiflex	.99	12.8	.97	11.1	.98	11.4

* SEM values are represented in Newtons

Inter-rater reliability of HHD force measures for each muscle action is presented in Table 32. For relative reliability, the ICCs for the 9 muscle actions were all higher than .80 (.84 - .94) indicating excellent inter-rater reliability agreement (between raters). Absolute reliability using SEM was between 11.1N and 24.3N. For the relative index, SEM% were small for all muscle actions (4.2 - 11.7%).

Inter-rater reliability for the PDT-Com Composite Scores is presented in Table 33. $ICC_{2,1}$ values ranged from .83 - .95, indicating the three raters had almost perfect agreement (462). All raters demonstrated ICC scores above .90 except for hip extension, which had an ICC of .83 (CI 95% = .71 - .91). For relative reliability, the ICCs for the 9 muscle actions were all higher than .80 (.84 - .94) indicating excellent inter-rater reliability agreement. Absolute reliability using SEM was between 11.1N and 24.3N. For the relative index, SEM% were small for all muscle actions (4.2 - 11.7%).

Table 32 **-** The relative and absolute reliability of lower-extremity strength measured by inter-rater reliability

Muscle Action	**ICC**	**95% CI for ICC**	**SEM**	**SEM%**
Hip Extension	.84	.78 - .89	22.8	11.7
Knee Flexion	.89	.83 - .93	11.2	11.5
Knee Extension	.91	.85 - .94	24.3	9.2
Hip Abduction	.94	.91 - .96	11.1	4.2
Hip Adduction	.87	.82 - .92	11.5	9.8
Hip Flexion	.92	.88 - .95	13.5	8.3
Ankle Inversion	.92	.87 - .95	11.7	9.0
Ankle Eversion	.91	.86 - .94	12.0	9.1
Ankle Dorsiflex	.86	.80 - .91	21.7	11.2

* SEM values are represented in Newtons

Table 33 **-** Inter-rater reliability of PDT-Com Composite Scores Comparing Raters 1, 2 and 3

Composite	**ICC**	**CI (95%)**	**Level of Agreement**
Hip LEFT	.92	.86 - .96	Almost Perfect
Hip RIGHT	.92	.86 - .96	Almost Perfect
Hip FLEXION	.91	.85 - .95	Almost Perfect
Hip EXTENSION	.83	.71 - .91	Almost Perfect
TOTAL Hip	.93	.88 - .96	Almost Perfect
LL RIGHT	.91	.85 - .95	Almost Perfect
LL LEFT	.91	.85 - .95	Almost Perfect
TOTAL LL	.92	.86 - .96	Almost Perfect
Left Leg TOTAL	.94	.89 - .97	Almost Perfect
Right Leg TOTAL	.94	.89 - .97	Almost Perfect
MOVEMENT	.92	.83 - .96	Almost Perfect
TOTAL Composite	.95	.91 - .97	Almost Perfect

* LL = Lower-limb

9.6 DISCUSSION

Researchers and clinicians within the field of falls prevention research continue to search for convenient, accurate and reliable assessments to assist in the targeted prescription of interventions to those at greatest risk of falling. Reliability is represented by multiple factors, absolute reliability and measurement error. The primary objective of this chapter was two-fold. Firstly, to determine the inter-rater reliability of the PDT-Com assessment protocol for measuring movement impairments in a healthy adult population aged 60 years and over (study one). Secondly, to determine the intra- and inter-rater reliability of the PDT-Com lower-extremity muscle strength protocol as measured using HHD in a similar population sample.

9.6.1 Summary of Main Findings

The results from studies one and two demonstrate that movement dysfunction and lower extremity muscle strength can be reliability assessed in healthy community-dwelling older adults using the PDT-Com protocol and a HHD when applied by trained healthcare professionals. With almost perfect agreement found for intra- and inter-rater reliability for both the assessment of movement dysfunction and lower extremity muscle strength, the results highlight the potential utility of the PDT-Com protocol for reliably identifying movement dysfunctions and assessing lower-extremity muscle strength in healthy adults aged over 60 years.

Impact of Gender

The results showed a statistically significant ($p < 0.001$) gender difference in mean force values for all muscle actions except knee extension ($p < .05$) and the lower-limb (ankle inversion, ankle eversion and ankle dorsiflexion). This lack of a statistically significant difference between male and female force values were surprising given that it has been shown that men exhibit greater muscle forces than their female counterparts (258). However, the estimates of force were greater for men by 8% for ankle inversion, 14% for ankle eversion and 6% for ankle dorsiflexion.

Assessment of movement dysfunction

Data from study one indicates that the assessment of movement dysfunction using the PDT-Com is reliable and can confidently be applied by suitably trained individuals when the standard procedure is used (Appendix H). The high weighted kappa (K_w) scores for all three movement assessments (range .85 - .92) indicated almost perfect agreement between both raters.

Assessment of muscle strength

The results from study two showed that lower-extremity muscle strength can be obtained reliably in one session by a single rater using the PDT-Com assessment protocol ($ICC_{3,1}$ = .92 - .98). Intra-rater reliability measures show high ICC (.91 - .99) and low SEM values (5.7N - 26.3N) indicating that each independent rater had almost perfect agreement. Furthermore, the inter-rater reliability of HHD force measurements in study two showed that relative (ICC) and absolute (SEM) reliability of all the muscle actions were excellent when measured by trained experienced assessors. However, both intra- and inter-rater reliability for the muscle force measurement of hip and knee extensors appeared to be slightly less reliable. Hip and knee extension SEM values showed a noticeably greater range across the raters (16.8N - 26.3N) compared to all other muscle actions. The mean SEM values for Rater 1, 2 and 3 were low (12.2N, 13.6N and 11.5N respectively) indicating small variability in values. As a result, it may be necessary to modify the testing position in future studies. Additionally, SEM% was small for each muscle group (4.2 - 11.7%) and was calculated to give a percentage value which is independent of the units of measurement. The SEM% is one type of relative index that represents the limit for the smallest change that indicates a real change for a group of subjects.

9.6.2 Comparison with Other Studies

Intra- and inter-rater reliability for the assessment of movement dysfunction and of lower-extremity muscle strength using HHD has not been widely studied in healthy older adults. Therefore, the discussion below draws on studies conducted in both health and clinical populations.

Movement dysfunction

Reported procedures for measuring movement dysfunction vary extensively in the literature, along with the type of instrumentation used, the method of data analysis, and the characteristics of the sample studied. For study one, the high K_w values observed for each movement are in line with previously published inter-rater reliability estimates obtained from similar constructs in previous studies. For example, a study by Minick *et al* (202) investigated the inter-rater reliability of the Functional Movement Screen (FMS) between two expert raters (FMS creators) and two novice raters (1 year of training). For the squat and lunge movements the pair of novice raters demonstrated K_w scores of .80 and .74 respectively (substantial according to Portney & Watkins (480)). When both sets of raters were compared, most of the ICCs were interpreted as excellent (> .80), with only 3 of 17 tests scores interpreted as substantial (> .60). Interestingly, the expert raters varied more in their scoring and had slightly lower ICC values for the squat (.64) and lunge (.53), indicating only moderate agreement. A similar study by Shultz (481), which examined reliability of the FMS, showed good reliability for the same rater (ICC = .60) but reported poor inter-rater reliability (Krippendorff α = .38). Shultz *et al* (202) also found raters with less experience had better agreement (fair), whereas raters with more than two years' experience had poor reliability (481). A study using only expert raters used the Athletic Ability Assessment

(AAA) (169) to assess squat, single leg squat and lunge ability, and reported moderate agreement between raters (.77; .55 and .36 respectively).

The results of this study indicate good reliability for the lunge movement assessment (K_w = .86) which is in agreement with Minick *et al* (202) and Frohm (482), but not Shultz (481), Teyhen (483) or McKeown (169), who found the inter-rater reliability of the lunge movement to be poor (.10, .45 and .36 respectively). In contrast, this study found the identification of dysfunction in the squat, lunge and SLSQ very reliable using experienced raters. However, the 95% confidence intervals for the lunge and SLSQ were wider (95% CI = .71 - 1.0 and .71 - .99 respectively) when compared to the squat suggesting some variability. There may be several reasons for this observation. Firstly, rater training tried to identify misinterpretations of the PDT-Com scoring criteria and correct them but this may not have been perfect. While the rater training aimed to correct any misinterpretations, training was not exhaustive due to time and resources and thus, errors may still have been present. Secondly, at times it was difficult to establish the presence of dysfunctions in the lower-limb due to video playback quality and the participants' clothing blending into the clinic surroundings. Additional scoring variability may also be attributable to the two-dimensional approach to retrospective video analysis. Thus, raters may benefit from multiple camera angles to assist in the analysis of the movements. However, this would make the protocol more difficult and timelier to complete and impractical for a setting where the use of multiple video cameras is not possible.

Muscle strength – test-retest (intra-rater) reliability

One of the earliest intra-rater reliability studies using HHD to assess muscle strength was by Bohannon in 1986 (213). Eighteen muscle groups were tested in subjects ranging in age from 17 - 79 years, though not all 18 muscle groups were tested on each subject. Data analysis revealed high Pearson's correlation coefficients (r = .84 - .99) when repeated measurements were taken by one experienced rater indicating good reliability. The results from study two in this thesis are in line with those from Bohannon *et al (99)*, with intra-rater reliability ICCs greater than .90 indicating almost perfect agreement. This agrees with several other studies which have explored the intra-rater reliability of measurements obtained using HHDs in healthy older adults. One such study by Schaubert and Bohannon (346) reported similar ICC scores for both dominant and non-dominant knee extensors (ICC = .92 and .93 respectively). These results are consistent with Bohannon (99), who reported that ankle dorsiflexion, knee extension, hip flexion and hip extension strength could be reliably obtained using a HHD in adults ranging in age from 20-79 years ($ICC_{3,1}$ = .94, .96, .95 and .95 respectively). In a study of older adults (Mean age 74.7 years) receiving home physiotherapy, Bohannon (484) also reported that knee extensor strength could reliably collected ($ICC_{3,1}$ = .94 - .98) using a HHD in a single session. More recently, a study on 18 older adults (aged 65 to 92 years) also reported good intra-rater reliability for isometric strength obtained by HHD at the hip, knee and ankle (ICC = .76- .93) (473).

Muscle strength – between rater (inter-rater) reliability

A summary of previous studies in this field is presented in Table 34. Arnold (473) used two independent raters to evaluate inter-rater reliability of HHD at the hip, knee, and ankle in 18 men and women (age 65 to 92 years). They reported that HHD has good inter-rater reliability for measuring strength at the hip and knee in older adults (ICC = .80 - .94), though not at the ankle (ICC = .48 - .62). Kilmer *et al* (485) also found that ankle dorsiflexion inter-rater reliability was unacceptable (ICC = .38), and found only a modest knee extension ICC value of .53. The latter value may have been the result of using inexperienced raters of varying strength levels and HHD stabilisation difficulties. In contrast, the results from study two in this chapter found ankle muscle action force measured by the 'make' test to have good inter-rater reliability for both male and female raters (ICC = .92 for inversion; .91 for eversion; .86 for dorsiflexion).

Table 34 - Summary of Studies Using ICC to Describe Inter-rater Reliability using HHD

Study	Participants (n)	Muscle Action	Side	ICC
Arnold *et al* (473)	Older Adults (18)	Ankle Dorsiflexion	Left	.62
			Right	.48
		Knee Extension	Left	.85
			Right	.80
		Hip Flexion	Left	.85
			Right	.82
		Hip Extension	Left	.94
			Right	.91
		Hip Abduction	Left	.89
			Right	.94
Kilmer *et al (485)*	Healthy Adults (11)	Ankle Dorsiflexion	Unknown	.38
		Knee Flexion	Unknown	.84
		Knee Extension	Unknown	.53
Richardson *et al (379)*	Older Adults (20)	Knee Extension	Right	.74
Thorborg *et al* (474)	Adults (50	Hip Flexion	Unknown	.90
		Hip Extension	Unknown	.91
		Hip Adduction	Unknown	.86
		Hip Internal Rotation	Unknown	.82
		Hip External Rotation	Unknown	.89

ICC = Intra-class correlation coefficient

Composite Scores

The results from study two showed that all but one (Hip Extension ICC = .83; 95%CI = .71 - .91) composite ICC values were greater than .90 demonstrating excellent inter-rater reliability. However, only five out of the nine ICC values for the individual muscle actions, that the composite scores were derived from, were above .90. McKeown *et al* (169) also reported higher ICC values for the AAA composite scores compared to the individual components of movement. They examined the intra- and inter-rater reliability of the AAA composite score using five experienced raters. The intra- and inter-rater values for the AAA Composite score were .97 and

.96 respectively, which is better than the scores reported in this study (ICC = .92; 95% CI = .83 - .97). In contrast, Ford-Smith *et al* (468) found slightly lower values (ICC = .71 - .74) for their composite scores (combined left and right sides for five muscle actions: hip extension; hip flexion; knee extension; knee flexion; ankle plantarflexion and ankle dorsiflexion) compared to individual left and right lower-extremity muscle action scores (ICC = .76 - .90). These values are also higher than the values reported for the FMS in several other studies (ICC = .38 - .91) (169, 482, 483, 486, 487). The ICC variability between studies is possibly due to several factors such as utilisation of differing methods of evaluation such as real-time and video-taped scoring, raters with varying levels of clinical experience, and elapsed time between test- retest sessions.

Interestingly, the hip extension composite ICC in this study, while classified as excellent, was lower (ICC = .83) than the others (ICC = > .90). Thus, implying that the test protocol may need modifying, or that additional rater training may be needed, to increase the ICC to the same high level as the other composite ICC values. The hip extension composite score is a combination of hip extension (ICC = .84; SEM = 22.8N) and knee flexion (ICC = .89; SEM = 11.2N) which were shown to have slightly less reliability and more variability in scores across the three raters. Difficulties with obtaining a reliable measure of hip extension strength have been widely discussed in the literature. A study by Lu *et al* (212) examined the reliability of different HHD test positions for hip extension and reported $ICC_{2,3}$ of the standing prone position (ICC = .92) to be higher than that for the prone position (ICC = .65). However, this is contrary to Krause *et al* who were unable to recommend a preferred hip extension testing technique (488). One possible reason for this variability is the challenge associated with the strength of subject relative to strength of the rater. For example, Krause *et al* (488) examined the influence of rater strength and HHD positioning on manual hip-strength testing reporting excellent intra-rater ($ICC_{3,1}$ = .82 - .97) and inter-rater reliability ($ICC_{2,1}$ = .81 - .98). They found significant differences between HHD positions and rater strength and recommended to use a long lever position to measure hip abduction. This problem is likely a reflection of rater bias, where the rater lacks the strength to stabilise the HHD in place when testing stronger subjects, and is a problem well recognised in the literature with larger lower-extremity muscle actions (100, 212, 221, 387, 464-466, 489-491).

9.6.3 Strengths, Limitations and Future Work

The main strengths are that it uses two separate studies to test the reliability of the PDT-Com, its use of a standardised HHD testing protocol and the use of raters with different experience and exposure to obtaining muscle strength measurements using HHD. It would have been erroneous to analyse the reliability of the whole PDT-Com assessment before first testing the reliability of each subsection. This is because the outcome data provided is both categorical (movement) and continuous (muscle strength). Therefore, two separate studies using different samples was conducted to determine the reliability the 'movement' and 'muscle strength' sections of the PDT-Com tool. The use of a standardised testing procedure reduces the variability in scores and enables better reproducibility of the study. Many HHD reliability studies do not publish or fully explain subject and rater testing positions which makes comparison across studies difficult. Furthermore, a strength of this study is the use of raters with different levels of experience and competency using HHD which may provide insight into the training time required to produce adequate test-retest values.

Both studies presented have several limitations which should be considered when interpreting the results. Firstly, the test-retest reliability measures were obtained in a single session separated by a 10-minute interval between tests. The reliability obtained over a period of days or weeks is much more relevant to health professionals who follow people over a period of time (388). The re-test period was deliberately short to reduce the burden on the participants and reduce possible fatigue bias. However, the short time between tests may have caused muscle fatigue in the subject and testing fatigue in the raters. Consequently, these results are not necessarily generalisable to re-testing over longer and potentially more unstable periods. Secondly, these results are limited by a small sample size. Although sample sizes are generally small in reliability studies due to practical and logistical constraints when measuring limb strength, a larger sample size would allow for more precision in our analyses (447). Another limitation, and a component of the PDT-Com movement analysis which may contribute to score variability, is the scoring criteria itself. One of the limitations noted in the PDT-Com movement tests was a restriction in the range of scores. Specifically, based on the ordinal scoring criteria, no participants scored a 1 or 6 for the squat, 1, 2 or 6 for the lunge test, and no participant scored 5 or 6 for the SLSQ movement. This restriction in range might have reduced the reliability estimates in the movement scores, particularly for the lunge. Furthermore, several dysfunctions are less clearly defined than others and can either be interpreted differently or not observed. This is particularly the case for identifying ankle pronation when the participant's dysfunction is present but less obvious.

This study and the results of future work will be used to further develop the PDT-Com movement scoring criteria and determine whether further modifications are necessary to better differentiate levels of performance in the three movement tests. Additionally, the pragmatic nature of this study meant that the two raters had repeated access to the PDT-Com video records and therefore, each rater may have watched the videos a different number of times. As a result, the reported K_w scores are not based on the same number of observations by each rater. However, it should be highlighted that this is likely to be the case in clinical practice i.e. the number of observations will differ amongst healthcare practitioners.

Finally, although the standardisation of the protocol and training of the raters is a strength of this study, the associated limitation is that the results may not be generalisable to inexperienced or inadequately trained health professionals. Experience and training time has previously been shown to affect reliability findings (202). Furthermore, the testing positions used in this study differ from those used in other studies and thus, different measurement errors may be introduced. Researchers and clinicians should check the reliability of their measurements when the testing protocol is different from those reported herein.

9.6.4 Clinical Implications

The PDT-Com is a standardised, reliable and valid assessment tool for identifying and objectively quantifying lower-extremity muscle action force and movement impairments in healthy older adults. This chapter suggest that suitably trained health professionals can obtain absolute and relative reliability values using HHD, and reliably identify movement impairments through a standardised scoring system in healthy older adults. The SEM, which is an index of absolute reliability, is a useful value for researchers to determine whether a change in a group is real and not due to measurement error. The SEM data presented in this chapter may provide useful information on measurement error in group comparisons for clinical research.

9.7 CHAPTER SUMMARY

The ability to clearly identify movement dysfunctions and lower-extremity muscle strength deficits in this population will assist health professionals in targeting poor movement patterns and muscle strength imbalances and may better direct an intervention. In this chapter, evidence was presented to support the validity and reliability of the PDT-Com. Two reliability studies were described that assessed the reliability of the movement and HHD sections of the PDT-Com, both of which demonstrated very good reliability for the individual muscle actions and the composite movement dysfunction scores. The PDT-Com was also found to have a high degree of internal consistency. While the psychometric properties of the new tool appear promising, future work is needed to obtain more precise results.

10 A RANDOMISED FEASIBILITY STUDY COMPARING AN EXERCISE PROGRAMME TO IMPROVE PHYSICAL FUNCTION VERSUS USUAL CARE IN COMMUNITY-DWELLING ADULTS AGED OVER 60 YEARS

10.1 INTRODUCTION

In the previous chapter a novel objective measurement tool for the assessment of physical impairments associated with a risk of falls in older adults has been presented and discussed. Chapter 6 established that the most commonly used objective measurement tool in this population was the hand-held dynamometer (HHD) and showed it correlated well with the gold standard. Chapter 7 highlighted the lack of objective muscle strength measurement tools currently available and these tools are being used at both the screening and assessment stages of the fall prevention pathway. With the components of the PDT-Com having been shown to be valid (Chapter 4) and reliable (Chapters 8 and 9) the final step in this thesis was to conduct a randomised feasibility study comparing the pre-and post-test scores of the PDT-Com.

National and international guidelines recommend that current assessment tools for identifying individual physiological risk factors for falling are improved (2, 492), along with the prescription of individualised exercise interventions following these assessments (314, 493). Several exercise interventions to improve lower-extremity strength, balance, physical function and to reduce falls have been found to be effective (64, 295, 494-496). Furthermore, a recent Cochrane review (64) concluded that exercise programmes that target two or more components of strength, balance, flexibility and endurance, reduces the rate (pooled rate ratio 0.71, 95% CI = 0.63 – 0.82) and risk (pooled risk ratio 0.85, 95% CI = 0.76 – 0.96) of falls in older adults. However, these programmes have been diverse in both their exercise prescription and delivery, including the setting, level of supervision and duration and intensity.

Two successful exercise programmes which encompass all of these components are the Otago Exercise Programme (OEP) (110) and the Fall Management Exercise programme (FaME) (109). The former is a home-based programme that targets strength and balance retraining in community-dwelling older adults. It has demonstrated benefit in several randomised trials using community-dwelling older adults above70 years (326) and above 80 years (497, 498). The FaME intervention is a 36-week group and home exercise programme incorporating fitness components plus specific falls management strategies. The FaME programme incorporates open, closed and backward chain exercises, functional and floor work and Tai Chi adapted moves (499).

Both OTAGO and FaME intervention programmes state they are individually tailored. However, it is necessary to make the distinction between exercise programmes that are 'Individually tailored' to those that are 'individually prescribed'. Tailoring is the process of establishing a baseline intensity/level that is suitable and making the necessary exercise progressions. Whereas individual prescribing is the process of selecting specific exercises based on a person's weaknesses, deficits and dysfunctions. It is not possible to individually prescribe exercises without being informed of specific muscle strength deficits, imbalances or dysfunctions. Within falls research, there are no commonly used assessment tools which have this ability.

No previous study has investigated the use of a comprehensive assessment tool to individually prescribe an exercise programme to improve physical function in older adults. Therefore, the aims of this study were to:

- establish acceptability of randomisation to potential participants
- establish feasibility of delivery of the PDT-Com assessment and intervention by multiple practitioners
- explore relationships between the PDT-Com and other commonly used measures of physical performance
- generate data on effects of PDT-Com intervention on physical performance measured by other commonly used tools
- assess and measure participants' acceptability and satisfaction of the PDT-Com programme
- refine PDT-Com intervention programme content.

10.1.1 Defining Feasibility and Pilot Studies

The words 'pilot' and 'feasibility' are both used in the literature to describe preliminary studies carried out before a larger or main study to evaluate the effect of an intervention or therapy. According to National Institute for Health Research (NIHR) guidelines (500) feasibility and pilot studies are mutually exclusive suggesting that feasibility studies are pieces of research done before a main study in order to answer the question 'Can this study be done?', and define pilot studies as a smaller version of the main study that is run in miniature to test whether the components of the main study can work together. However, this contrasts with the Medical Research Council's (MRC) framework (501) which states 'a pilot need not be a scale model of the planned main-stage evaluation, but should address the main uncertainties that have been identified in the development work. These conflicting interpretations of what constitutes a pilot or feasibility study may explain the differences in usage and opinion observed in the literature. Whilst some authors recommend these definitions in truth there is no general consensus.

In response to the diverse views concerning the definitions of pilot and feasibility studies within the research community Eldridge and colleagues (502) developed a conceptual framework within researchers can operate when designing and reporting pilot/feasibility studies in preparation for an randomised controlled trial assessing the effect of an intervention or therapy. The authors concluded researchers view feasibility as an overriding concept, with all studies done in preparation for the main study open to being called feasibility studies with pilot studies as a sub-set of feasibility studies (502). This suggests that a feasibility study occurs slightly earlier in the research process and that a pilot study is effectively a miniature version of the main trial.

10.1.2 Rationale for Conducting a Randomised Feasibility Study

The primary purposes of a feasibility study are to ensure that study implementation is practical and to reduce threats to the validity of the study's outcomes (503). There are several reasons for conducting this feasibility study. Firstly, it enables us to test the acceptability of randomisation of participants to either the intervention or no intervention group. Secondly, it presented us with preliminary data on the comparison of the PDT-Com and intervention verses control on short-term outcome measures (physical function). Thirdly, it provided data on the comparison of the effects measured by PDT-Com and other commonly used measurements of physical function. Alternatively, a non-randomised feasibility study could have been completed but this would not allow testing consent and randomisation and would not give such relevant data for a subsequent trial.

10.1.3 Research Questions

Primary research questions:

Q_1 what is the effect of a three-month targeted intervention in older adults living in the community on physical function outcomes measured using the PDT-Com compared to the TUG, BBS and 30sCRT?

Q_2 how does the PDT-Com compare as a measure of physical function to the TUG, BBS and 30sCRT?

Secondary research question:

Q_1 what are participants' perceptions and satisfaction with the PDT-Com assessment procedure and subsequent three-month targeted exercise intervention?

10.2 METHODS

10.2.1 Study Design

This research addresses short-term physical outcomes and not falls risk or incidents of falls. It is a pragmatic, randomised feasibility study with a three-month follow up. This follow-up period allows time for the programme to be completed and physical abilities to improve in the intervention. Participants were randomly allocated to a control group (no intervention) or an exercise intervention group.

10.2.2 Randomisation

Participants were randomised on an individual basis using a computer generated random number sequence to determine the allocation of the interventions. An independent statistician at Warwick Clinical Trails Unit generated the random number sequence.

Allocation - Randomisation was according to a computer-generated randomisation schedule. A remote third-party telephone randomisation system, based at Warwick clinical trials unit, was used for allocating individual participants to the trial arms.

Blinding of intervention allocation - While the allocation sequence was concealed from the study researcher, it was not possible to blind the study researcher or therapists delivering the intervention to the allocation following randomisation. Furthermore, it was not possible to blind participants to their allocation due to the nature of the intervention.

10.2.3 Subjects

Healthy, independent, community-dwelling older men and women (n=30; Age >60 years) were invited to participate in this study (Table 35). Eligibility for participation was determined by a therapist at initial assessment using a self-report questionnaire (Appendix J). Criteria were: those aged 60 years and older who can walk independently of personal help both indoors and outdoors (with or without the assistance of a walking aid), and those who were physically able to participate in a small group exercise class. Those with any of the following were excluded:

- not living independently (i.e. nursing homes or residential care homes)
- already receiving physiotherapy treatment (> twice/week)
- severe visual impairment
- psychiatric conditions or marked cognitive impairments

- systemic illnesses (pneumonia, uncontrolled angina, acute rheumatoid arthritis, unstable or acute heart failure) or neurological disease or impairment whereby intensive exercise may be contraindicated

Table 35 - Characteristics of Study Subjects (*n* = 30)

	Age (yrs.)		Height (m)		Weight (kg)	
Gender	**Mean**	***SD***	**Mean**	***SD***	**Mean**	***SD***
F (n=19)	67.3	5.3	1.63	0.08	67.4	14.9
M (n=11)	66.8	4.9	1.75	0.04	83.6	12.1

10.2.4 Recruitment and Setting

Participants were invited to participate from local voluntary organisations (The Percival Guildhouse, Rugby), local yoga classes, a GP surgery and word of mouth in the area of Rugby, Warwickshire. A contact person at each organisation publicised the study and people expressing an interest in participating were asked to provide contact details to the study chief investigator who formally invited them via text, telephone or email. Supervised group exercise sessions took place at a private injury rehabilitation centre in Rugby, which currently provides various exercise classes to community-dwelling older adults in the form of Tai Chi, yoga, Pilates and general exercise for older adults.

10.2.5 Assessors

All assessments were conducted by either a physiotherapist or sports therapist who were experienced in the delivery of musculoskeletal assessments. Two of the three therapists were employees at Peak Performance rehabilitation centre, Rugby and one was a middle-grade academic researcher at the Clinical Trials Unit, Warwick Medical School. All therapists attended six hours of additional training in the administration of all four test measures. This included repeatedly practicing the tests on the other assessors to become competent in order to execute each test accurately and in a time-efficient manner.

10.2.6 Procedures

Baseline characteristics (gender, age, height, weight and lower-body dominant side) were collected. All participants were tested at baseline and at three-months after randomisation. Full details of the PDT-Com, TUG, BBS and 30sCRT assessment procedures can be found in Appendix H, I, J and K respectively. These specific tests were selected because of their wide spread use in the clinical setting and use as outcome measures in fall prevention studies. In brief, all participants were invited to attend and complete all assessments at the beginning and at the end of the study. After completion of baseline assessments, they were then randomised to receive the intervention the control, described below.

10.2.7 Ethical Approval and Informed Consent

Full ethical approval by the University of Warwick's Biomedical and Scientific Research Ethics Committee was obtained (REGO-2016-1884 – see Appendix M). Participation in this study was entirely voluntary. All prospective participants received a Participant Information Sheet (detailing the study background, rationale, and procedures) (Appendix O) and consent form (Appendix N). Only those who had signed a consent form could take part in this study. Participants could withdraw from the study at any time.

10.2.8 Sample Size

The aim of the feasibility study was to provide some initial data on the effects of PDT-com that can inform the planning of a larger trial (502, 504). However, there is little in the way of specific guidance on appropriate feasibility study sample sizes in the literature. There was no formal sample size calculation because the trial is not testing a therapy to determine its effectiveness. However, sample sizes of 24–50 participants have been recommended for assessing the feasibility of an intervention (505, 506). Therefore, a sample size of 30 participants was considered to be sufficient to explore the feasibility and the potential effect of PDT-Com on outcomes.

10.2.9 Description of Trial Interventions

There were two intervention arms to this trial:

1. Exercise Group (EG)

The exercise intervention was a three-month home and group exercise-based programme informed by the findings from the PDT-Com assessments – each participant was prescribed an individually tailored exercise programme. The programme was broadly designed to identify and reduce muscle strength deficits, muscle strength imbalances, flexibility restrictions and poor movement using a comprehensive physical assessment procedure (PDT-Com) followed by a prescription of targeted exercises based on each participant's PDT-Com score. Intervention exercises consisted of a 20-30-minute individualised programme of lower-extremity floor-based exercises to target the following muscle actions: knee extension/flexion, hip abduction/adduction, and ankle dorsiflexion, inversion and eversion. Functional balance retraining exercises were designed to be progressed in difficulty, to be performed at home at least three times per week. These exercises consisted of the following: squats (double and single-leg), lunging, heel/toe walking, single-leg standing (stable and unstable surfaces) and sit to stand exercises. A 60-minute supervised (individual or group) whole-body functional exercise session (emphasis on the squat, lunge, sit-to-stand exercise and single-leg squat) and manual therapy (specific joint mobilisations and self-myofascial release techniques) was arranged for participants to attend at least once per week.

In each subject's first session they received a small instruction booklet and rubber band/tubing to provide resistance for selected floor-based exercises. They were introduced to their respective homework exercises by the therapist and started at an appropriate level based on respective PDT-Com assessment results. Each supervised group session contained no more than six subjects. There were four available group sessions arranged each week. Programme adherence was facilitated by a training diary (507).

2. Control Group (CG)

This group continued with their regular or usual physical activity or exercises and did not receive an individualised exercise intervention programme. Therapists did not recommend or prescribe any particular physical activity.

10.2.10 Outcome Measures

a) Physical Performance

The primary outcome was 'physical performance' which was measured at baseline and at three-months. This was a composite outcome which included the following: overall PDT-Com composite score, TUG, BBS and 30sCRT scores. Previous studies have shown the TUG, BBS and 30sCRT to have good test-retest reliability (ICC = 0.95–0.97; ICC = 0.97; ICC = 0.89 respectively) (114, 340). Secondary outcomes included the following: 1) the differences in Total and subscale PDT-Com composite scores (hip to knee muscle strength, knee to ankle muscle strength, movement competency) between TUG, BBS and 30sCRT test scores post three-month intervention, 2) participants' perceptions of acceptability and satisfaction with the PDT-Com programme (Appendix E).

b) Acceptability and Satisfaction (Intervention Group only)

Questionnaire development was achieved by using examples from existing literature and several discussions with two other researchers in the field of falls prevention. After multiple iterations a consensus was reached regarding the most appropriate questions to include. Questions about acceptability and satisfaction were themed by exercise domain (group or home), and a final question regarding programme recommendation to friends/family members. Group exercise session quality of service questions (1 – 7; and question 12) were rated on a 5-pioint Likert-like scale (poor, fair, good, very good, excellent). For the home exercise questions (8 – 10), subjects rated their degree of agreement (strongly disagree, disagree, agree, moderately agree, strongly agree), while the recommendation question asked the likelihood of a referral to a friend or family member in the future (certainly not, probably not, not sure, yes probably, yes certainly would recommend).

10.2.11 Statistical Analysis

All data was analysed on an intention-to-treat basis using SPSS (version 21). This is an important aspect of randomised clinical trials and interventions. An intention-to-treat analysis is considered the optimal statistical approach as it analyses the participants according to the groups they were originally assigned (508). By applying these principles, this analysis yields an unbiased estimate of the efficacy of the intervention on the primary study outcome at the level of adherence observed in a trial (508, 509). Characteristics of participants were compared at baseline. Descriptive statistics were presented for baseline data. For outcome measures, the mean difference (MD) and 95% confidence intervals (CIs) are presented. Normality of data was assessed graphical using a histogram. A paired-samples (repeated measures) t-test was used to assess pre-post test scores within each group. To compare the changes of outcome measures in TUG, BBS, 30sCRT and PTD-Com between groups at three months a one-way analysis of covariance was used (ANCOVA). If the data were not normally distributed, the Mann-Whitney-U test was used to asses between group scores, and the Wilcoxon signed rank test was be used to assess within group change (450, 471).

To examine the relationship between the PDT-Com, TUG, BBS and 30sCST the following PDT-Com composite scores were considered: (1) total, (2) total hip dominant side, (3) total hip non-dominant side, (4) lower-limb dominant side, (5) lower-limb non-dominant side, (6) total left side, (7) total right side, and (8) movement competency score. Each of these conditions were correlated with the TUG, BBS and 30sCRT scores. The Pearson product moment correlation coefficient (PCC) was used to calculate correlations.

10.3 INTERVENTION COMPLIANCE

Compliance with the home exercise programme was monitored using exercise diaries to record frequency and duration. Participants were asked to record reasons for non-compliance.

10.3.1 Adverse Events

An Adverse Event (AE) was defined as any untoward medical occurrence did not necessarily have a causal relationship with this intervention. With regards to the exercise intervention, some muscle soreness was to be expected after stretching and strengthening exercises. Any other type of adverse events was recorded in a log by the therapist instructing the group exercise session and reported to the chief investigator’s academic supervisors. Since this was a small exploratory randomised feasibility study involving group exercise, there was no Trial Steering Committee or

Data Monitoring and Ethics Committee. The study did have a trial management group, consisting of the researcher's supervisory team (Professor Simon Gates and Professor Julie Bruce). Study AEs were recorded using an appropriate notification form (Appendix K).

10.3.2 Serious Adverse Events

In non-CTIMP trials, a serious adverse event (SAE) is defined as an untoward occurrence that: a) results in death; b) is life-threatening; c) requires hospitalisation or prolongation of existing hospitalisation; d) results in persistent or significant disability or incapacity; e) consists of a congenital anomaly or birth defect; or f) is otherwise considered medically significant by the investigator. Study SAEs were recorded using an appropriate notification form (Appendix L).

10.3.3 Serious Adverse Event reporting procedure

A SAE occurring to a research participant were reported to the trial management group where in the opinion of the Chief Investigator the event was:

- Related – that is, it resulted from administration of any of the research procedures,

AND

- Unexpected – that is, the type of event was not listed in the protocol as an expected occurrence.

A 'directly attributable' SAE were only recorded and reported if the event occurred during contact time with the healthcare professional delivering the intervention or while undertaking study exercise, either supervised or unsupervised. This applied to an SAE which was life-threatening, required hospitalisation, resulted in persistent or significant disability or incapacity, required medical attention to prevent one of the above or was considered medically significant by the investigator. This did not apply to expected events such as delayed onset muscle soreness or infection (as described in Section 4.12 above).

10.4 PARTICIPANT CONFIDENTIALITY & DATA SECURITY

Appropriate practical arrangements were in place to maintain the integrity and security of all research study data. Personal information (name, email addresses and phone numbers) was recorded and retained securely in a locked filing cabinet. Study data (questionnaires and video files) was anonymised and stored securely in either locked filing cabinets or electronically on password protected and encrypted computers. Study data will be retained for a recommended minimum period of 10 years after the completion of the research study unless informed otherwise by a relevant regulatory body or ethics committee. Both project supervisors had access to study data; however, they were not able to identify participants. The results of this study will be submitted for publication.

10.5 BENEFITS & RISKS

There were no financial benefits from taking part in this study. However, on completion of the study participants had the opportunity to ask questions about the results of their functional assessment. A copy of each test results for each participant was available on request. The main risks of taking part in this study were minor muscle and joint aches and pains. There was also a risk of falling over, fractures (from falling) and cardiovascular events; however, previous research has shown these events to be extremely rare. Sometimes people experience mild soreness, particularly in the legs, for a few days following assessment. This was considered normal and there were no anticipated long-term negative effects.

10.6 FINANCING

This study was conducted as part of a PhD research project and was not funded by an external body or institution.

10.7 CONFLICTS OF INTEREST

The chief investigator and one of the trial therapists are Directors of Peak Performance, Rugby. The PDT-Com assessment is an adaptation of the Performance Deficit Test™ used by Peak Performance. Peak Performance and its Directors did not receive any financial reward or gain from the use of the PDT-Com assessment.

10.8 RESULTS

10.8.1 Recruitment

A total of 34 older adults were screened as being potentially eligible to participate in this study. After initial consultation, two were not eligible due to medical reasons and two withdrew their interest. The remaining 30 gave signed consent and were recruited into the study as shown in Figure 40. A total of seven participants (23.3%) withdrew over the three-months of follow-up; thus three men and four women withdrew prior to the final assessment at three-months and data for these subjects was not included in the final analysis.

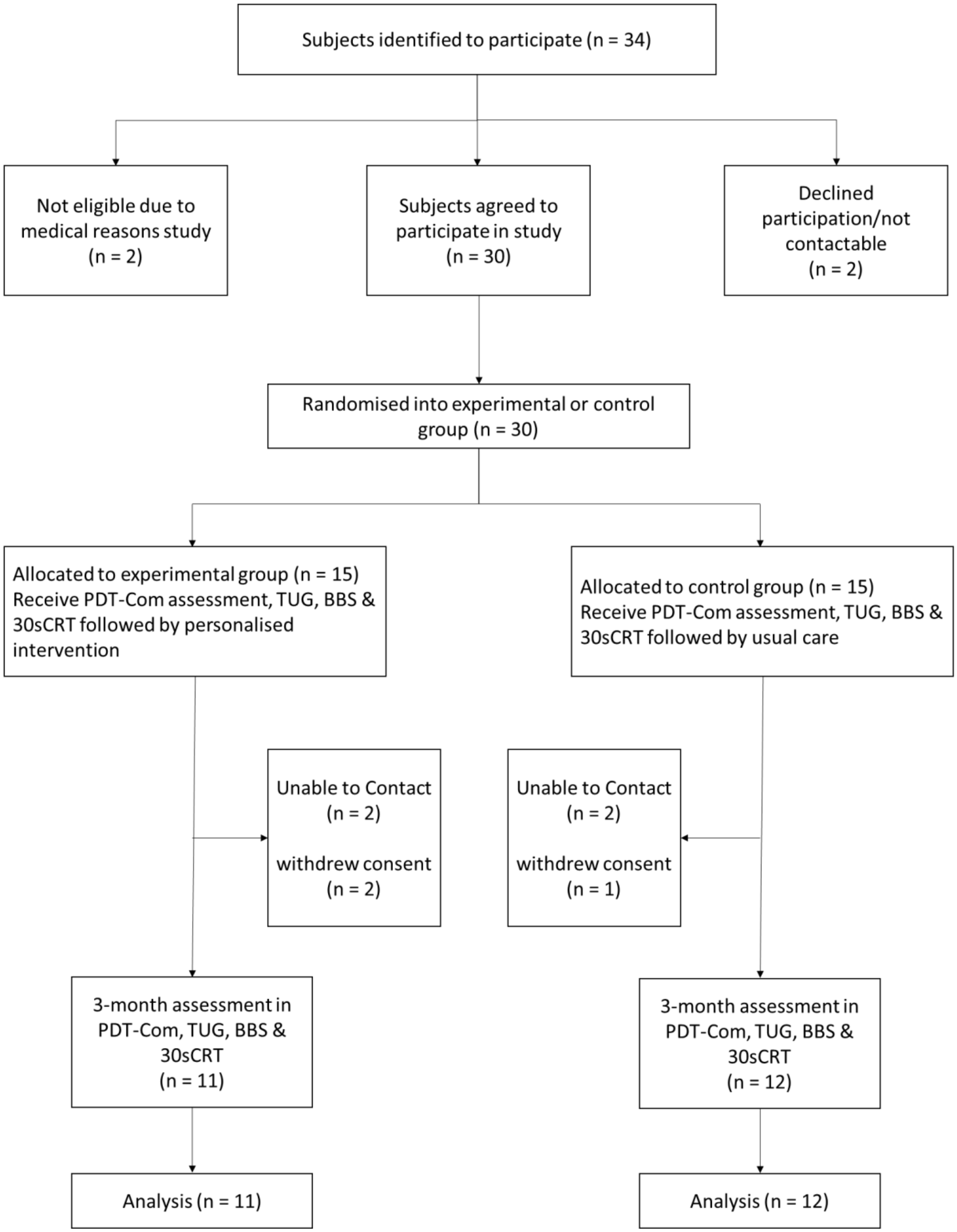


Figure 40 - CONSORT schematic of prospective flow of participants

Key: PDT-Com = Performance Deficit Test; TUG = Timed-Up-&-Go Test; BBS = Berg Balance Scale; 30sCRT = 30 second Chair Rise Test

10.8.2 Baseline Characteristics

The baseline characteristics of subjects are shown in Table 36. The sample age ranged from 60 to 78 years (*M* = 67.7, *SD* = 5.1), with more women (*n* = 19) than men (*n* = 11) taking part. There were no statistically significant differences between groups for any of the baseline characteristics ($p \leq .05$). The 30sCRT and TUG are both tests of subjects' functional capacity. The TUG findings indicated that all subjects in both groups did not have a mobility issue or were considered to be at risk of falling at baseline (*M* = 6.2, *SD* = 1.1) (347, 510). However, according to 30sCRT normative data one male subject in the control group and one female in the exercise group were considered to have a gait, balance or functional impairment (114). No statistical comparisons were done using the BBS because all participants in both groups achieved a score of 100% at baseline and at three-months.

Table 36 – Baseline Characteristics of Study Participants by Randomised Groups

	Control Group (± *SD*)	**Exercise Group (± *SD*)**	
Characteristic	***n* = 15**	***n* =15**	***p***
Males /Females	6 / 9	5 /10	-
Age (yrs.)	67.3 (5.5)	67.0 (4.8)	.89
Height (m)	1.67 (0.08)	1.67 (0.09)	.93
Weight (kg)	69.4 (16.2)	77.3 (15.0)	.17
Total PDT Scores (%)	69.7 (13.8)	66.9 (13.2	.57
PDT Dominant Hip (%)	70.7 (18.9)	69.3 (18.4)	.83
PDT Non-Dominant Hip (%)	72.2 (17.9)	69.6 (18.0)	.69
PDT Dominant lower-limb (%)	76.6 (12.1)	72.5 (18.6)	.47
PDT Non-Dominant lower-limb (%)	73.6 (17.0)	67.8 (18.6)	.38
PDT Total Dominant Side (%)	73.1 (14.3)	70.5 (16.9)	.65
PDT Total Non-Dominant Side (%)	72.8 (16.3)	68.9 (15.9)	.51
PDT Movement Scores (%)	45.9 (10.4)	48.9 (12.1)	.48
30sCRT	18.6 (2.4)	18.4 (3.8)	.86
TUG Scores (s)	6.1 (1.1)	6.3 (1.0)	.77

Notes: Values express mean (± standard deviation); yrs. = years; m = meters; kg = kilograms; PDT = Performance Deficit Test; 30sCRT = 30 second Chair Rise Test; TUG = Timed Up & Go; s = seconds; Notes: higher scores in the TUG indicate a decrease in performance

10.8.3 Compliance and Adverse Events

There were 12 group exercise sessions over a three-month period. Compliance with group exercise sessions was moderate with the mean attendance rate of 61.1% (Table 37). Subjects were asked to complete two home exercise sessions each week. Home exercise compliance was moderately high with 75% of subjects reporting that they completed two exercise sessions each week. None of the subjects reported any adverse or serious adverse events during the trial.

Table 37 **–** Exercise Group Attendance

Session Type	Number of Sessions	Attendance (%)
Group		
	6 sessions or less	33
	Over 6 sessions	67
	Mean Attendance	61.1
Home		
	≥ 2 session/week	75
	< 2 session/week	0
	0 session/week	0

10.8.4 Primary Outcomes

Within Group Analysis

Primary outcome measures by group at baseline and at three-months are presented in Table 38. To test within group differences a paired samples *t*-test was performed. For the exercise group, the mean Total PDT score after a three-month exercise intervention was significantly higher (79.8%, *SD* = 11.8%) from baseline (66.5%, *SD* = 14.2%), *p* = < .001. Mean 30sCRT scores at three-months (21, *SD* 7.1) were significantly greater than at baseline (18, *SD* = 4.2), *p* = .045. However, mean TUG scores were not significantly different at three-months (6.8s, *SD* 1.8s), compared to baseline (6.4s, *SD* = 1.1s), *p* = .196. All PDT composite scores for the exercise group were statistically significant at three-months compared to baseline (Table 39), except PDT movement scores which were greater at three-months (63.1%, *SD* = 21.1%) compared to baseline (48.5%, *SD* = 13.8%), but did not reach statistical significance (p = .51).

For the control group, mean Total PDT score was lower at three-months (70.2%, *SD* = 12.2%) than at baseline (72.6%, *SD* = 11.3%), but this did not reach statistical significance (p = < .12) (Figure 41). However, improved performance of the 30sCRT at three-months (21, *SD* = 1.6) compared to baseline (19, *SD* = 1.5) was statistically significant (p = .01). Additionally, a significant increase in mean time taken to complete the TUG was observed at three-months (6.5, *SD* = .58s) compared to baseline (5.9s, *SD* = .77s), p = .04, indicating a decrease in performance (Figure 42). For PDT composite scores there were no significant improvement in scores at three-months compared to baseline (Table 36). However, decreases in three-month mean scores for PDT movement (41.7%, *SD* = 9.3%) and PDT non-dominant hip (69.7%, *SD* = 12.3%) did reach statistical significance (p = .01 and p = .04 respectively).

Table 38 – Primary outcome measures by group at baseline and at three-months

Outcome Measures		Control Group					Exercise Group				
		n	**Mean (*SD*)**	***MD***	***p***	***d***	***n***	**Mean (*SD*)**	***MD***	***p***	***d***
Total PDT-Com											
	Baseline	15	72.6 (11.3)	-2.4	.117	0.49	15	66.5 (14.2)	13.3	.000**	2.04
	three-months	12	70.3 (12.2)				11	79.8 (11.8)			
30sCRT											
	Baseline	15	19 (1.5)	1.9	.007**	0.95	15	18 (4.2)	3.0	.045*	0.69
	three-months	12	21 (1.6)				11	21 (7.1)			
TUG[a]											
	Baseline	15	5.9 (0.8)	0.7	.038*	0.68	15	6.4 (1.1)	0.4	.196	0.42
	three-months	12	6.5 (0.6)				11	6.8 (1.8)			

Key: PDT = Performance Deficit test; 30sCRT = 30 second Chair Rise Test; TUG = Timed-Up-&-Go Test; *MD* = mean difference; *d* = Cohen's *d*;
** difference significant at the .01 level; * difference significant at the .05 level; [a] = higher scores in the TUG indicate a decrease in performance

Table 39 – PDT composite outcome measures by group at baseline and three-months

		Control Group					Exercise Group				
PDT-Com Composite Scores		***n***	**Mean (*SD*)**	***MD***	***p***	***d***	***n***	**Mean (*SD*)**	***MD***	***p***	***d***
Non-Dominant Hip											
	Baseline	15	76.8 (14.1)	-7.2	.012*	0.83	15	69.9 (18.6)	8.8	.041*	0.71
	three-months	12	69.7 (12.3)				11	78.8 (15.6)			
Dominant Hip											
	Baseline	15	74.7 (16.2)	-5.1	.072	0.58	15	69.9 (19.3)	12.9	.004**	1.10
	three-months	12	69.7 (17.0)				11	82.8 (12.8)			
Non-Dominant Lower-limb											
	Baseline	15	75.7 (16.4)	2.8	.333	0.29	15	64.3 (18.0)	22.8	.000**	1.86
	three-months	12	78.6 (16.6)				11	87.1 (15.3)			
Dominant Lower-limb											
	Baseline	15	77.7 (11.8)	6.6	.082	0.55	15	70.1 (18.4)	17.8	.000**	1.99
	three-months	12	84.4 (9.9)				11	87.9 (15.6)			
Total Non-Dominant side											
	Baseline	15	76.4 (13.3)	-3.2	.094	0.53	15	67.7 (15.9)	14.9	.000**	1.57
	three-months	12	73.2 (13.3)				11	82.3 (11.6)			
Total Dominant side											
	Baseline	15	76.0 (11.9)	-0.4	.850	0.06	15	69.9 (17.6)	14.5	.000**	1.80
	three-months	12	75.6 (13.3)				11	84.8 (12.8)			
Movement Composite											
	Baseline	15	47.7 (3.7)	-6.0	.036*	0.69	15	48.5 (13.8)	14.7	.051	0.67
	three-months	12	41.7 (9.3)				11	63.1 (21.1)			

Key: *MD* = mean difference; *d* = Cohen's *d*;

** difference significant at the .01 level; * difference significant at the .05 level;

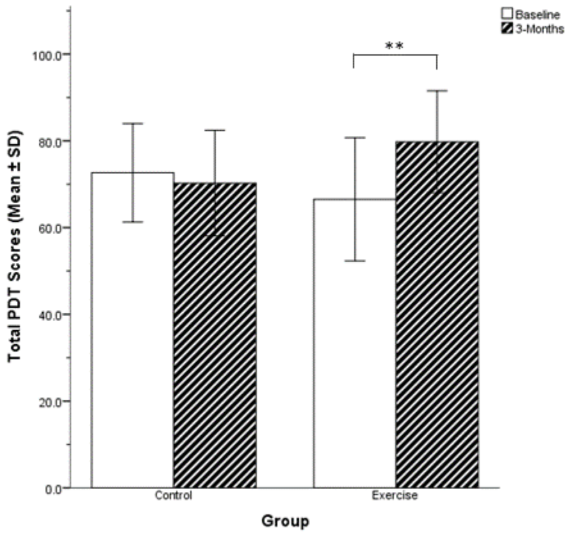


Figure 41 - Bar chart showing comparison between baseline and three-months Total PDT-Com Scores for both groups

** p = < .01; * p = < .05

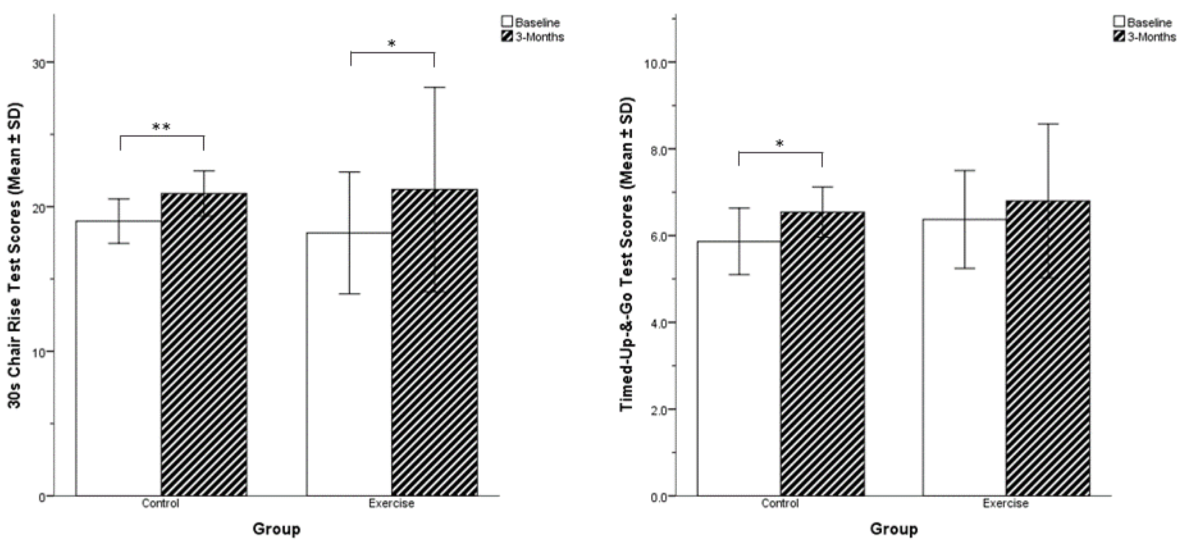


Figure 42 - Bar charts showing comparison between baseline and three-month 30 second Chair Rise Test (30sCRT) (left) and Timed-Up-&-Go Test (TUG) (right)

** p = < .01; * p = < .05. Notes: higher scores in the TUG indicate a decrease in performance

Between Group Differences

A one-way analysis of covariance (ANCOVA) was performed to compare the effectiveness of an individual exercise intervention on PDT-Com, 30sCRT and TUG outcome measures. Results of the analysis are presented in Table 40. Participant's baseline performance was used as the covariate in this analysis. The mean Total PDT, 30sCRT and TUG scores in the exercise group were 79.8% (SD = 11.8%), 21.2 (SD = 7.1) and 6.8s (SD = 1.8s) respectively, compared to the control group (70.3, SD = 12.2%; 20.9, SD = 7.1; and 6.5s, SD = .58s respectively).

After adjusting for baseline Total PDT performance, the main effect of a three-month exercise intervention was statistically significant, $F(1, 20) = 39.07$, $p < .001$, indicating that increases in Total PDT score were greater for the exercise intervention group (M = 82.5%, 95% CI = 78.9 – 85.9%) compared to the control group (M = 67.8%, 95% CI = 64.5 – 71.1%) (Figure 43). However, for the 30sCRT there was no statistically significant differences between the exercise group (M = 21.7, 95% CI = 19.6 – 23.8), and control group (M = 20.4, 95% CI = 18.4 – 22.5), $p = .380$. Similarly, there was no significant difference between TUG performance for the exercise group (M = 6.6s, 95% CI = 5.9 – 7.2s), compared to the control group (M = 6.7s, 95% CI = 6.1 – 7.4s), $p = .695$ (Figure 44).

For all PDT composite scores, statistically significant between group differences were observed at three-months (Table 40).

Table 40 – Unadjusted and Adjusted estimates of effect in primary and PDT composite scores at three-months

Variable	Control Group (n = 12)				Exercise Group (n = 11)					
	Unadjusted Mean	95% CI	*Adjusted* Mean[a]	95% CI	*Unadjusted Mean*	95% CI	*Adjusted* Mean[a]	95% CI	p	η_p^2
Primary Outcomes										
PDT Total Score (%)	70.3	63.1 – 77.4	67.8	64.5 – 71.1	79.8	72.3 – 87.3	82.5	78.9 – 85.9	.001**	.66
30sCRT	20.9	17.9 – 23.9	20.4	18.4 – 22.5	21.2	18.0 – 24.3	21.7	19.6 – 23.8	.380	.04
TUG (s)[b]	6.5	5.8 – 7.3	6.7	6.1 – 7.4	6.8	5.9 – 7.6	6.6	5.9 – 7.2	.695	.01
PDT Composite Scores										
PDT Dom Hip (%)	69.7	60.5 – 78.8	68.1	62.6 – 73.5	82.8	73.3 – 92.3	84.6	78.9 – 90.3	.001**	.48
PDT Non-Dom Hip (%)	69.7	61.3 – 78.1	67.5	61.9 – 73.1	78.8	70.0 – 87.5	81.2	75.3 – 86.9	.002**	.38
PDT Dom Lower-limb (%)	84.4	76.6 – 92.2	82.1	76.6 – 87.7	87.9	79.8 – 96.0	90.4	84.5 – 96.2	.049*	.18
PDT Non-Dom Lower-limb (%)	78.5	68.8 – 88.1	74.5	68.2 – 80.8	87.1	77.1 – 97.2	91.5	84.8 – 98.0	.001**	.42
PDT Dom Side (%)	75.6	67.7 – 83.4	73.4	69.1 – 77.8	84.8	76.6 – 93.1	87.2	82.6 – 91.7	.001**	.50
PDT Non-Dom Side (%)	73.2	65.7 – 80.7	70.2	66.0 – 74.3	82.3	74.4 – 90.1	85.6	81.2 – 89.9	.001**	.57
PDT Movement Score (%)	41.7	32.0 – 51.3	41.8	32.3 – 51.4	63.1	53.1 – 73.2	62.9	52.9 – 72.9	.005**	.34

KEY: PDT = Performance Deficit Test; 30sCRT = 30 second Chair Rise Test; TUG = Timed-Up-&-Go Test; Dom = Dominant; (s) = Seconds; η_p^2 = partial eta squared

** difference significant at the .01 level; * difference significant at the .05 level; [a] = means adjusted for the covariate (baseline Total PDT-Com score; [b] = higher scores in the TUG indicate a decrease in performance

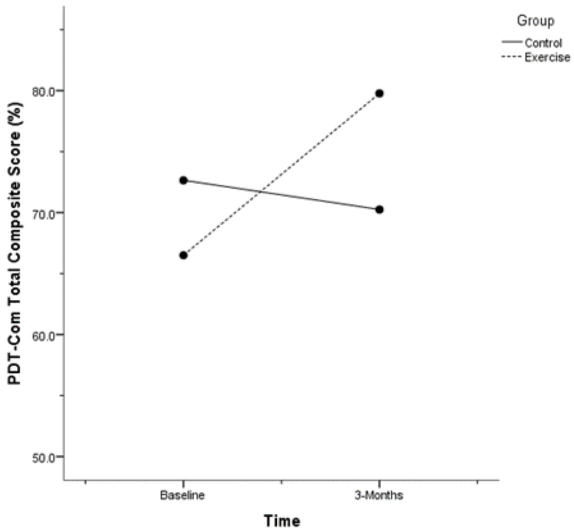


Figure 43 - Line chart of the mean Total PDT-Com scores for the control and exercise groups at baseline and after three-months for both groups

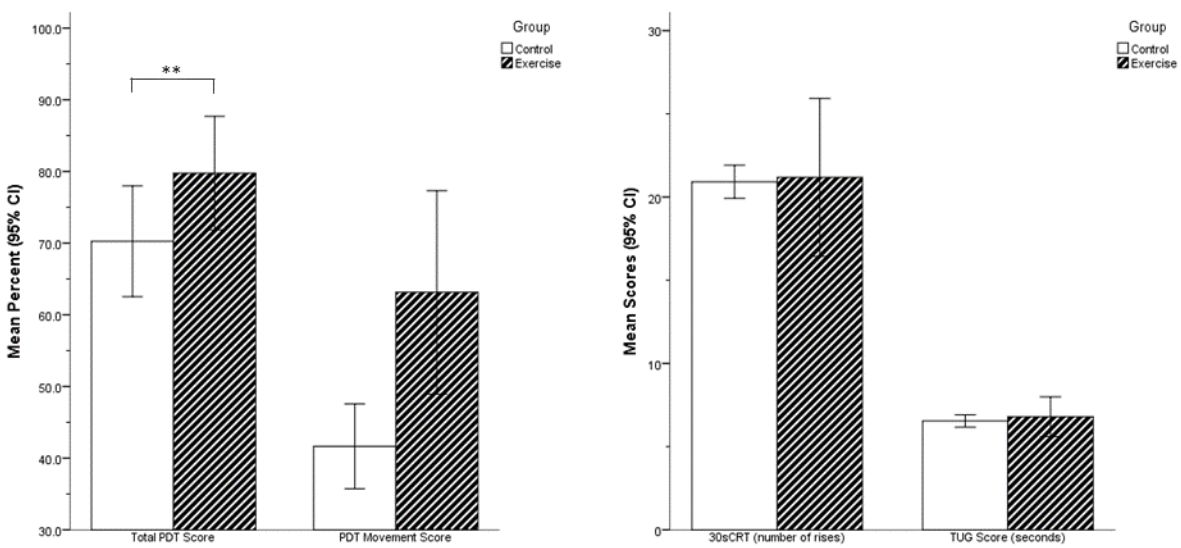


Figure 44 - Bar charts showing between group differences in Total PDT and PDT movement scores (left) and 30sCRT and TUG scores (right) after a three-month exercise intervention.
** *p* = < .01

Relationships between Outcome Measures

The Pearson's correlation coefficient was used to examine the linear relationships between all variables (Table 41). Both the 30sCRT and TUG were moderately inter-correlated (r = -.556, p = < .05), suggesting that increases in the number of chair rises was correlated with improved TUG performance (Figure 45). Inter-correlations were observed between Total PDT score and all outcome variables (r = .690 - .955, p = < .001), except the 30sCRT (r = .418, p = < .05) and TUG test (r = -.390, p = > .05) which both showed a moderate correlation (Figure 46).

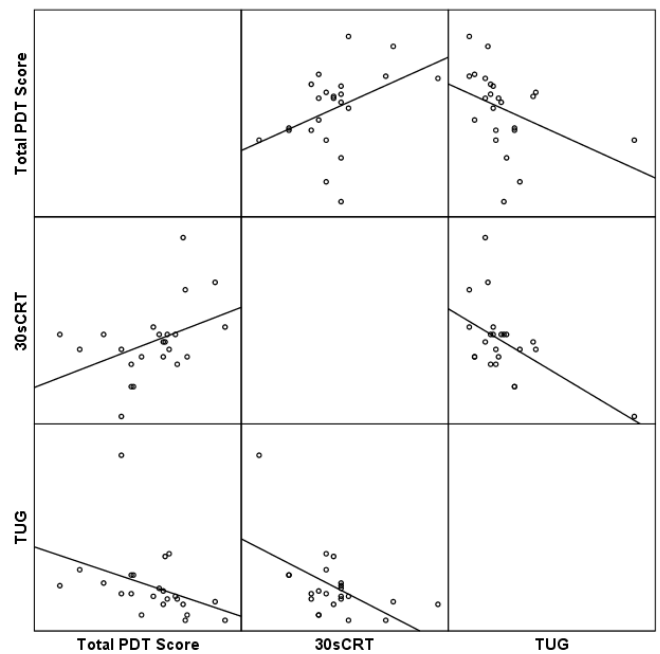


Figure 45 – Scatterplot matrix showing direction and strength of association between selected outcome variables at three-months.

The 30sCRT was significantly correlated with Total, dominant lower-limb and total dominant side PDT scores. On the other hand, the TUG test was only significantly correlated with the non-dominant hip PDT scores which indicates that there is a moderate negative correlation between the variables. PDT movement scores were significantly correlated with all variables, except PDT dominant lower-limb, 30sCRT and TUG test.

Table 41 – Pearson's Correlation Coefficient values for target variables

		2	3	4	5	6	7	8	9	Total PDT Score
1	PDT Dominant Hip	.790**	.644**	.708**	.876**	.958**	.719**	.367	-.223	.937**
2	PDT Non-Dominant Hip		.354	.475*	.897**	.699**	.789**	.396	-.532**	.833**
3	PDT Dominant L-Limb			.802**	.636**	.836**	.296	.443*	-.229	.690**
4	PDT Non-Dominant L-Limb				.814**	.808**	.414*	.227	-.105	.805**
5	PDT Total Non-Dom Side					.866**	.733**	.371	-.407	.955**
6	PDT Total Dominant Side						.625**	.429*	-.245	.930**
7	PDT Movement Score							.401	-.406	.791**
8	30s Chair Rise Test								-.556**	.418*
9	Timed-Up-&-Go									-.390

**. Correlation is significant at the .01 level; * Correlation is significant at the .05 level.

10.8.5 Satisfaction and Feasibility Analysis

The intervention satisfaction questionnaire (Appendix I) was administered at three-months to the exercise group only (n = 11, missing data, n = 4). Descriptive data are presented in Tables 42 and 43.

Group exercises

For the group sessions, 40% of subjects said the ability of the therapist to explain the content of each session was ‘very good’, with 20% saying it was ‘excellent’. The ease of access to the facility, and the comfort of the room, was rated as ‘good’ to ‘excellent’ by 60% of subjects. The ability to put the subjects at ease, along with the quality of information received, was rated as ‘excellent’ by 40% of subjects. While 47% of subjects rated the comfort of the room as being ‘very good’. The general quality of the group sessions was rated as very good or excellent by 73% of subjects.

Home exercises

For the home exercise sessions, 67% of subjects either moderately or strongly agreed that the contents of the exercise booklet were clear. With respect to agreeing the exercises were worth their time to do, 73% moderately or strongly agreed that they were, while 40% moderately agreed they received the guidance they needed during the programme. Furthermore, most subjects (33%) agreed that they could complete the exercises without much difficulty, compared to 13% who strongly agreed with this statement. Most subjects (47%) rated the overall quality of the exercise intervention programme as excellent, and most of the subjects (68%) strongly agreed they would recommend the exercise programme to a friend.

Table 42 – Subjects ratings regarding feasibility of the group exercise intervention

	Count (%)				
Questions for group exercise feasibility (*n* = 11, missing data, *n* = 4)	**Poor**	**Fair**	**Good**	**Very Good**	**Excellent**
1 - How would you rate the therapist's ability to explain what you will be doing during each exercise session?	-	-	2 (13)	6 (40)	3 (20)
2 - How would you rate the ability of the therapist to put you at ease?	-	2 (13)	1 (7)	2 (13)	6 (40)
3 - How would you rate the extent to which the exercises were adapted to your needs?	-	-	1 (7)	8 (53)	2 (13)
4 - How would you rate the comfort of the room where the exercise session took place?	-	-	1 (7)	7 (47)	3 (20)
5 - How would you rate the quality of information you received during your group sessions?	-	1 (7)	2 (13)	2 (13)	6 (40)
6 - How would you rate the ease of access to the group exercise facility?	-	-	2 (13)	5 (33)	4 (27)
7 - How would you rate the overall quality of the group exercise sessions you received?	-	-	-	7 (47)	4 (27)

Table 43 – Subjects' agreements relating to home exercise and overall satisfaction

Statements relating to home exercise and overall feasibility (*n* = 11, missing data, *n* = 4)	**Count (%)**				
	Strongly Disagree	**Disagree**	**Agree**	**Moderately Agree**	**Strongly Agree**
8 - The directions in the instruction booklet were clear?	-	-	1 (7)	5 (33)	5 (33)
9 - The exercises were worth my time to do?	-	-	-	4 (27)	7 (47)
10 - I could do the exercises without much difficulty?	-	-	5 (33)	4 (27)	2 (13)
11 - I received the guidance I needed from the instruction booklet?	-	-	2 (13)	6 (40)	3 (20)
12 - How would you rate the quality of the service you received?	-	-	1 (7)	3 (20)	7 (47)
13 - If a friend needed similar help, would you recommend our program to him or her?	-	-	-	1 (7)	10 (67)

10.9 DISCUSSION

The aims of this randomised feasibility study were to establish acceptability of randomisation to potential participants and feasibility of delivery of the PDT-Com intervention by multiple practitioners, explore relationships between PDT-Com and other measures of physical function, generate data on effects of PDT-Com intervention measured by other commonly used tools, and to assess participants' perceptions and satisfaction with the PDT-Com assessment and intervention programme. The allocation procedure was robust, and no serious adverse events were reported. The exercise intervention was well tolerated with no issues relating to the reporting or conduct of the home exercise. At the end of a three-month individual exercise programme, mean Total PDT scores for the exercise group were significantly improved compared to baseline scores. Conversely, mean PDT scores in the control group decreased at three-months compared to baseline scores. Significant between groups differences in mean PDT scores were observed at three-months suggesting that those subjects receiving an individualised exercise programme improved in their physical function compared to the control group. Each of the key findings is discussed in more detail below.

10.9.1 Feasibility of Intervention Delivery

The results of this study suggest that therapists with prior knowledge and experience in using HHD is feasible. The therapists in this study all had several years' exposure to HHD testing. However, to further improve consistency and accuracy an additional six hours of training (2 hours/week) prior to the start of data collection was provided. It was beyond the limitations of this study to determine if this volume and frequency of training would be sufficient for therapists without any experience in using HHD or similar data collection methods. Online or video learning tools may be useful for information and theory but the practical nature of data collection using

HHD makes this mode of learning ineffective. These results also suggest that different therapists can effectively deliver an individually tailored intervention directed by each participant's assessment data.

10.9.2 Relationships between Assessment Tools

Large statistically significant inter-correlations (r = .79 - .95; p = .01) were observed between Total PDT-Com score and all PDT-Com composite scores. The 30sCRT and TUG were moderately correlated in this study, suggesting increases in the amount of chair rises correlated with TUG performance. These results were consistent with other studies which showed similar values. In a study by Applebaum *et al* (511), moderate to strong correlations were found (r = -.63, p < .01) between a modified 30sCRT and the TUG test. However, correlations between the BBS, 30sCRT and TUG tests could not be done due to the ceiling effects of the BBS scores in this study. Previous research (512) has found only moderate correlations between the BBS and TUG (r = .51; p = .01).

The 30sCRT showed only moderate correlations with Total (r = .42; p = <.05), dominant lower-limb (r = .44; p = <.05) and total dominant side (r = .43; p = <.05) PDT-Com scores in this study. These results are comparable to those by Lord *et al* (513) who also found moderate correlations between the 30sCRT and three measures of muscle action strength using hand-held dynamometry (r = .37 - .43; p = <.05). Furthermore, a study by McCarthy *et al* (514), reported similar results (r = .21 - .52; p = <.05) when examining the correlations between the 30sCRT and six measures of lower-extremity muscle action strength (hip extension; hip flexion; knee extension; knee flexion; ankle dorsiflexion; ankle plantarflexion). In contrast, only weak correlations were found (r = .3 - .4; p = <.05) between isometric strength measures in a sample of 1,038 older adults (515). The results of this study, coupled with previous research (513, 514), suggests there are other variables that explain 30sCRT performance. Additional independent variables, such as leg speed, leg power, leg endurance, posture, injury history, and fear of falling, may also explain the variance in 30sCRT performance. Therefore, this study shows that lower-extremity muscle actions are important indicators, but only partially predict performance of a 30sCRT. This finding is important considering the reliance placed on this test by health professionals to assess lower-extremity muscle strength in older adults.

PDT-Com movement scores were significantly correlated with all other measured variables, except for the PDT dominant lower-limb, 30sCRT and the TUG test. To date, there are no other studies that examine the relationship between movement quality and other measures of physical function in an older adult population. In this study, strong correlations were reported between movement ability and composite scores of the dominant and non-dominant hip (r = .719 and .789 respectively; p = .01), suggesting hip complex muscle strength scores may be more important than lower-limb muscle strength for performance of good movement during transitional movements. Interestingly, studies reporting the importance of the contribution of lower-limb muscles in the execution of chair stands have not reported movement competency (513). Therefore, the reported reliance on several muscles of the lower-limb may have been a result of compensation strategies due to reduced force output in hip complex muscle actions e.g. hip extension/flexion/adduction/abduction and knee flexion/extension.

10.9.3 Effects of PDT-Com Intervention

The exercise group mean score for the 30sCRT improved from 18 to 21 chair rises over three-months. Similarly, the control group improved in their 30sCRT performance (21) compared to baseline (19). The 30sCRT is designed to assess lower-extremity muscle strength during a functional task and is strongly correlated (r = .71 - .78) to the weight adjusted one repetition maximum leg press (114). According to normative data (114) for a similar age range (68-70 years), both group's 30sCRT performance was comfortably above the expected range of between 12.9 and 14 chair rises. However, there were no significant between group differences in performance at three-months. It is possible the control group subjects who did not complete the three-month assessments may have affected the scores. The subgroup who completed the three-month tests had a mean baseline score of 17 for the 30sCRT, while the subgroup who did not complete the three-month tests had a lower baseline mean score of 13. Thus, the observed increase in 30sCRT performance at three-months for the control group may be due to the withdrawal of less physically able subjects.

The TUG test is a short, simple and widely used clinical performance-based measure of balance and functional mobility in community-dwelling, frail older adults (331). Although a decrease in TUG test performance at three-months was observed for the exercise group, this did not reach statistical significance. However, for the control group a significant decrease in TUG performance at three-months was observed compared to baseline. Furthermore, there was no significant between group differences in TUG test performance at three-months. Overall, the exercise group TUG mean scores increased from 6.4s at baseline to 6.8s at three-months. Although performance marginally decreased over time, these times are well below recommended cut-off scores required to be classified as having a mobility issue or at risk of falling (347, 510). Again, it is possible that the control group scores were affected by those subjects who withdrew as the withdrawal sub-group had a baseline mean TUG score of 7.3s compared to 5.9s for those that remained in the study.

The mean data for the TUG test in this study is lower (faster) than that reported previously in community-dwelling older adults (331, 340, 516, 517). In a study using a similar population (n =

96; Age = 61 – 89 years), Steffen *et al* (340) recorded mean TUG scores of 8, 9 and 10 seconds for 60 – 69-year olds, 70 – 79-year olds and 80 – 89-year olds respectively. In a more recent study (517), TUG scores of 9.1s (*SD* = 1.6s) were recorded when comparing healthy older adults to stroke patients. A cut-off score of 13.5 seconds has been suggested to identify persons with an increased risk of falling for community-dwelling older adults (347). In contrast, a lower threshold of 12 seconds or less has been recommended by Bischoff *et al* (518) to identify normal mobility in community-dwelling older adults. The present results and those of previous studies, confirm that different populations and circumstances require different cut-off points. In healthy community-dwelling older adults, the suggested cut-off point of ≤12 seconds to determine normal mobility may need to be lowered further.

All subjects scored the maximum possible scores for the balance test at baseline and at three-months. Clearly, the BBS is a psychometrically sound measure of balance impairment for use in several clinical domains (332-334, 430). Furthermore, the acceptance of the BBS is evidenced by its frequent use as a validation standard for other physical performance measures, such as the TUG test. However, due to the ceiling effects reported in several populations (336, 519), health professionals may want to use the BBS in conjunction with other tests of physical function. Despite these obvious limitations, the BBS scores are still used to make important clinical decisions about screening, intervention and progression. It may be beneficial to use different and more challenging physical performance tests to detect deficits in balance, strength and movement ability in active community-dwelling older adults.

10.9.4 Participants' Satisfaction and Acceptability

The mean attendance rate for study group sessions was just over 60% with two-thirds of subjects attending over half the sessions. Also, compliance with the recommended two home sessions each week was good overall, at 75%. It is possible that greater differences in outcomes could have been achieved if compliance to the home and group exercise sessions was maximised. However, it is well documented that adherence to exercises prescribed for the home environment is challenging (520). The adherence rates in this study appear impressive when compared to other studies, some of which report adherence rates as low as 10% (521). However, others have reported adherence rates as high as 82% , 95% (25), and 100% (294) for group and home-based exercise programmes. The OEP and FaME programmes exceed the recommended number of exercises for older adults to maintain their health (297, 298, 300). Therefore, decreasing the number of exercises by using the PDT-Com assessment to prescribe individual exercises may further improve adherence.

10.9.5 Limitations

This study is limited by its small sample size (*n* = 30), particularly for the assessment of physical function, and while the statistical results give an indication of potential effect, the study was not powered to determine effectiveness. The ability to apply the results of this study to the general older adult population is limited by the homogeneity of the sample (active community-dwelling men and women, with no apparent underlying medical or musculoskeletal conditions), and the use of specialist muscle force measuring equipment (hand-held dynamometer). While participants who volunteer for studies of exercise interventions are generally motivated to change, this may have contributed to the success of the intervention programme and thus affect broader generalisability to less motivated or frailer older cohorts. Additionally, it was beyond the scope of this study to directly compare results with existing programmes such as the Otago and FaME interventions. Although these results are promising, this is only a feasibility study and as such underpowered. Therefore, results of this study must be interpreted with caution.

10.9.6 Implications and Future Work

The results of this small randomised feasibility study suggest that a three-month home/group exercise programme is an acceptable and feasible option to improve physical function in those older adults aged 60-70 years. Although falls were not captured as outcomes in this study, the usefulness of the BBS, TUG and 30sCRT in identifying and monitoring physical fall risk factors in this population is questionable/limited. The 100% score on the BBS, coupled with comparatively high performance in the TUG and 30sCRT indicates these assessments may not be suitable for assessing higher-functioning older adults or those at the lower end of the age spectrum. More challenging assessments, such as the PDT-Com, may better reveal strength deficits, balance problems and movement dysfunctions that could eventually contribute to falls in people who are higher-functioning.

Larger trials are needed to further investigate the effect of individual exercise prescription on deficits and improvements in physical functioning, which are on the pathway to falling, or inhibit adaptations to the intervention. In addition, further research with those older adults identified as a fall risk is needed to accurately assess the role of an individually prescribed exercise approach using the PDT-Com assessment tool.

10.10 CHAPTER SUMMARY

In conclusion, this study suggests that a short three-month individual exercise programme is a safe, feasible and acceptable option as an exercise intervention programme in community-dwelling older adults to improve physical function. The mean Total PDT-Com scores for the exercise group were significantly improved compared to baseline scores. Conversely, mean PDT-Com scores in the control group marginally decreased over time from baseline scores. Significant between groups differences in mean PDT-Com scores were observed between groups suggesting that those subjects receiving an individualised exercise programme improved their physical function compared to the control group.

11 OVERALL SUMMARY, LIMITATIONS, FUTURE RESEARCH AND CONSIDERATIONS

11.1 INTRODUCTION

11.1.1 Aims and Objectives of the Thesis

The aim of this thesis was to contribute to the existing evidence base for the assessment of falls risk in community-dwelling older adults. As a strength & conditioning coach, the author sought to further develop and rigorously whether a novel physical assessment tool, named the **P**erformance **D**eficit **T**est for **Com**munity-Dwelling older adults (PDT-Com), could better detect potential modifiable physical impairments associated with fall risk in healthy community-dwelling older adults. The secondary purpose was to examine whether this assessment tool could be used to better direct an individualised targeted exercise intervention. Ultimately, the aims were:

- To systematically review the literature to determine a valid, reliable and feasible tool for the objective measurement of lower-extremity muscle strength in this population (see Chapter 6)
- To systematically review the literature regarding existing assessment tools that are used at the multifactorial fall risk assessment (MFRA) stage. Specifically, to investigate their construct and measurement characteristics to see if the data collected by each tool matched the abstract constructs that underlined the measures (see Chapter 7)
- To conduct a study to collect reference values for isometric lower-extremity muscle action force using hand-held dynamometry (HHD) (see Chapter 8)

- To evaluate both intra- and inter-rater reliability of the newly developed PDT-Com assessment tool in a community-dwelling older adult population (see Chapter 9)
- To conduct a randomised feasibility controlled trial to compare PDT-Com to the TUG, BBS and 30sCST as a test of physical function and to evaluate the feasibility and acceptability of using the PDT-Com in this population (see Chapter 10)

11.2 OVERVIEW OF THESIS FINDINGS

11.2.1 Chapter 3 – PDT-Com Assessment and Scoring Criteria

The underlying conceptual framework and development process of the PDT-Com assessment tool was presented in Chapter 2 and the key points are as follows. Several concepts in the development of a new tool designed to assess physical function and movement competency were outlined. These included, but were not limited to:

- Lower-extremity muscle strength
- maintaining precise movement
- impairments of the Human Movement System
- ankle, knee and lumbopelvic instability
- ankle mobility
- knee stability
- lower-extremity muscle strength

This was followed by an outline of the foundational understanding of the kinematics and kinetics of the ankle, knee, lumbopelvic hip complex and thoracic spine during three transitional movements (squat, lunge, and single leg squat). A key finding was that three simple bodyweight transitional movements had the potential to be used to better understand the movement strategy of an older adult prior to the prescription of an exercise intervention. It can be concluded that health professionals may benefit from using these physical function tests to assist in the design of exercise interventions, and to ensure the adaptations forthwith contribute to an increase in physical performance rather than injury or an increase in risk of falling.

11.2.2 Chapter 4 – The PDT-Com Scoring System

In Chapter 4, development of the PDT-Com movement competency scoring criteria for the movement was outlined. This consisted of observing transitional movement patterns based on human movement system principles (96). Movement competency for the squat, forward lunge and single leg-squat were scored on a 1-6 ordinal scale. Other assessment tools were found to have adopted similar scoring methods and criteria, and to have proven valid and reliable in the paradigms of injury rehabilitation (149, 198, 200) and strength & conditioning (90, 97, 121, 169, 172), from within the frameworks of community-dwelling middle-aged and older adult populations (361, 362). Another study established lower-extremity muscle action force reference values in healthy community-dwelling older adults. Two raters obtained these values by hand-held dynamometer. This data was used to develop an accurate and reliable scoring system that was used to test the reliability of the PDT-Com.

11.2.3 Chapter 5 – Literature Review

The key points for the literature review presented in Chapter 5 are as follows. The numbers of fallers in the older adult population is a major public health problem in many countries across the world. Falls have a devastating effect in terms of morbidity, mortality and loss of independence, placing a large burden on the UK healthcare system. Intrinsic, or physiological, risk factors for falls have been found in different epidemiological studies. These potentially modifiable factors are many and include impairments in gait function, balance ability, deficits and asymmetries in lower-extremity muscular strength, joint range of movement (ROM) and biomechanical alignment. However, despite this evidence our health care system, and those of other western countries, is primarily focused on discovering treatments and cures for disease rather than directing efforts towards prevention.

The WHO Global Report on Falls Prevention in Older Adults (2) made recommendations that future research should focus on improving the assessment of individual factors that increase the likelihood of falls; and facilitate the design and implementation of appropriate, evidence-based interventions that will significantly reduce the number of falls among older adults. Similar proposals and recommendations have been communicated by several other international organisations and institutions. In the UK, a joint article by the American and British Geriatric Societies (5, 15) stated that all multifactorial interventions for community-dwelling older adults should have an exercise component. Furthermore, the guidelines specify exercise programmes should include balance, gait, and strength training, such as Tai Chi or physical therapy, in group programmes or as individual programmes at home. Most falls are the result of the interaction of multiple factors, and the greater number of factors an individual has the greater propensity to fall. To identify those at risk is to maximise the effectiveness of any prescribed exercise intervention. It is also part of the process that acknowledges and responds to the WHO Global Report in Falls Prevention in Older Adults (2).

Based on the systematic literature review (Chapter 7), the importance of maintaining adequate lower-extremity muscle strength for functional independence was paramount. While the successful completion of daily activities was also emphasised as essential to the maintenance of lower-extremity muscle strength, its direct measurement in fall prevention research was notably limited. The effects of this limitation were further compounded by the fact that - by their very definition and per the descriptor ‘community-dwelling’ - distinctly more active than their institutionalised counterparts. Tools used in other paradigms, such as the Functional Movement Screen and the Athletic Ability Assessment, were evaluated and understood as able to respond to the needs of this more active population to a certain extent. Although they were found to provide valid and reliable measures of physical function in younger more active populations, however, they were also found to be inadequate to the requirements of an older adult population. A strong need was outlined for tools useful to the direct measurement of lower-extremity muscle strength, particularly within the context of an older community-dwelling population.

The conceptual framework underpinning injury risk factors in strength and conditioning science, and assessment tools like the PDT-Com, may go some way to advancing current practice in fall prevention research. Health professionals may benefit from using these functional performance tests to assist in the more targeted design of exercise interventions, and to ensure the adaptations forthwith contribute to an increase in physical performance rather than injury or an increase in risk of falling.

11.2.4 Chapter 6 – Systematic Review – The Measurement of Muscle Strength

In Chapter 6, a systematic review of objective muscle strength assessment tests was presented. Its aim was to critically appraise, compare and summarise the measurement properties of tools that measure lower-extremity muscle strength in community-dwelling older adults aged over 65 years. It was established that depending on the setting, outcome and number of muscle actions requiring testing any of the measurement tools identified may provide the health professional with valid and reliable data. A key finding was that measurement tools providing extensive data

(Stationary and Isokinetic Dynamometer) are more suited to clinical settings where quantification of joint torques, force curves and contraction types are required. In light of this finding, the HHD, Nintendo Wii Board and Myometer were considered more suitable due to the cost of isokinetic devices and the impracticality of daily or repeated testing. Interestingly, other tools were shown to have high ICC values (Leg Press Machine, Keiser A420 and Nintendo Wii Board) but were found to be limited in their testing capacity, and only provided data on single muscle actions (knee extension) when in some instances health professionals who may want to test multiple areas. Another key finding was where the need for testing was required away from a clinical setting, and where multiple measurements of several different muscle actions are needed, the HHD, with or without belt resistance, and a Myometer was most suited. However, if the requirement for relatively fast and accurate measure of functional strength the simple method proposed by Sato *et al* (384) may be more suitable.

This chapter on objective muscle strength measurement tools adds to the current literature supporting the use of objective measurement devices such as isokinetic dynamometers and HHD. The assessment of muscle strength is an important clinical consideration for older adults at risk of falling. The ability to determine what devices are valid, reliable and feasible in this population may help health professionals decide when and how to use them.

11.2.5 Chapter 7 - Systematic Review – Fall Risk Assessment Tools

In Chapter 7, a systematic review of fall risk assessment tools was presented. Its aim was to identify assessment tools that were developed for use on healthy community-dwelling older adults after initial risk screening, and to summarise these tools' ability to detect modifiable physical impairments in this population. It was established that previous systematic reviews examined the predictive ability of falls assessment tools in different populations and across different age groups (29, 393), but that no review had assessed the ability of falls risk assessment tools to accurately measure potentially modifiable physical risk factors in this population. A key finding was that assessment tools conceptualised lower-extremity muscle strength as the ability to accomplish some form of functional task, with performance being measured either on a nominal (dichotomous) or ordinal scale. It was argued in turn that this method of scoring may be better relegated to the sphere of quantifying mobility/movement impairments, and that in its place a direct (objective) measurement of muscle strength deficits should be favoured.

Another key finding was the ambiguity surrounding the distinction between screening and assessment. According to the American Geriatric Society/British Geriatric Society guideline, the concept of screening is distinct from the more intensive assessment and intervention process (15). The ProFaNE Taxonomy Domain 3 (C200) (75) does not make this distinction between screening and assessment however and actually even conflates the two. To be more precise: it not only defines screening as a short test to determine an older adult's risk of falling, but also and the same time puts forward the notion of the assessment process as a diagnostic test to determine an older adult's risk of falling. This lack of differentiation between the screening and assessment process may explain why most of the assessment tools' objectives are to predict, categorise and/or distinguish fallers, rather than to identify underlying causes of falls.

The early detection of known modifiable physiological risk factors was also highlighted as essential if the end-goal is to reduce falling through targeted exercise intervention. If the intervention involves exercise, then it is important that an assessment process determines what specific areas of the body need modification for each individual. Such an assessment, complete with other constructs of human physical performance (e.g. strength, balance, gait etc.), need to be tested in a clinical setting. The results presented in this chapter clearly strengthen support for these recommendations and reinforce the need to adopt a multifactorial and multi-disciplinary approach that uses and applies all the constructs associated with human physical performance to fall risk assessments in community-dwelling older adults. The conceptual framework underpinning injury risk factors in Strength & Conditioning science, and assessment tools like the PDT-Com, may go some way to advancing current practices in fall prevention research.

11.2.6 Chapter 8 – Obtaining Reference Values Using HHD

Chapter 8 detailed the experimental study that set out firstly to quantify the test re-test reliability of hand-held dynamometry by two raters during a single session and secondly;–to collect reference data for 10 lower-extremity muscle actions in healthy community-dwelling older adults. The reference values and ranges generated by this research were identified as potentially useful in a clinical setting, particularly insofar as they were able to measure strength deficits within lower-extremity muscle groups among healthy community-dwelling older adults. The data is useful to a clinician in the context of assessing individual muscle groups, or in the context of a broader test battery to establish a general picture of a person's lower-extremity strength.

These data may also be useful for further studies investigating who is likely to fall as well as in the development and prescription of individually prescribed exercise intervention programmes targeting the lower-extremity. This information has the potential to be used to assess and monitor healthy community-dwelling older adults for muscle strength deficits, and with further research on a larger population, may be useful in the identification of fall risk factors and the development of an individualised exercise intervention programme.

11.2.7 Chapter 9 – Assessment Tool Reliability

Having thus far established the need for an assessment tool to measure lower-extremity muscle strength in an older community-dwelling population and having established a scoring system that could correctly express its requirements, Chapter 9 documented steps taken to conduct an experimental study of the reliability of the proposed PDT-Com tool. Two studies were described in their assessment of the reliability of movement and HHD sections of the PDT-Com. Both reliability of movement and HHD sections were found to demonstrate stable results for the individual muscle actions and for the composite movement dysfunction scores. The PDT-Com was also found to have a high degree of internal consistency. It was acknowledged that although the psychometric properties of the new tool appear promising, future work is needed to obtain more precise results. The studies described in Chapter 9 suggested that suitably trained health professionals could not only obtain absolute and relative reliability values using HHD, but also consistently identify movement impairments through a standardised scoring system in healthy older adults. It was established that the PDT-Com was a standardised, reliable and valid assessment tool for identifying and objectively quantifying lower-extremity muscle action force and movement impairments in healthy community-dwelling older adults.

Although the standardisation of the protocol and training of the raters was a strength of this study, the associated limitation is that the results may not be generalisable to inexperienced or inadequately trained health professionals. Experience and training time has previously been shown to affect reliability findings (202). Furthermore, the testing positions used in this study differed from those used in other studies and consequentially, different measurement errors may have been introduced.

11.2.8 Chapter 10 – Randomised Feasibility Study

The final step in this thesis was to conduct a randomised feasibility study comparing the pre-and post-test scores of the PDT-Com (and PDT composite scores), the 30sCRT, TUG and BBS following a 3-month individualised exercise intervention. This trial showed that at the end of a 3-month individual exercise programme, mean Total PDT scores for the exercise group were significantly improved compared to baseline scores. Conversely, mean PDT scores in the control group decreased at 3-months compared to baseline scores. Significant between groups differences in mean PDT scores were observed at 3-months suggesting that those subjects receiving an individualised exercise programme did better than the control group.

As a feasibility study, this trial demonstrated that a 12-week home and group exercise programme was well tolerated with no adverse or serious adverse events reported. The results also suggest that a 3-month home/group-based exercise intervention was a well-tolerated, feasible, acceptable and safe method for improving physical function in community-dwelling older adults. This was supported by formal feedback and ratings provided by the subjects in response to the intervention.

11.3 SUMMARY OF LIMITATIONS OF THIS THESIS

Limitations of each study within this thesis have been discussed in individual chapters. However, it is valuable to revisit the main themes before making statements regarding further research and considerations.

11.3.1 Hand-Held Dynamometry

One of the benefits of using hand-held dynamometry is the relative costs and portability compared to a criterion referenced standard Isokinetic Dynamometer. However, there is still a marked cost implication of approximately £600 - £1,000 depending on model type that may limit the ability of health professionals in utilising the PDT-Com assessment.

Although the reliability of hand-held dynamometry (HHD) is well established (101, 218, 221, 222, 485, 522, 523), it has been suggested that reliability is highly dependent on standardised testing procedures and examiner (tester) strength to overcome the muscle group being tested (219, 464). The latter becoming apparent in Chapter 8 where rater strength may have been responsible for producing moderate test re-test reliability scores when measuring plantar flexion force.

11.3.2 Systematic Review

Since the systematic review of Chapter 7 was conducted (search included articles published up to 2014) it is possible that new fall risk assessment tools, or modifications of existing tools, may have been developed. In addition, it was not possible to have the articles screened using the eligibility criteria by a second reviewer due to time constraints.

11.3.3 Assessment Tool Development

The version of the PDT-Com assessment used in this thesis is the long- or clinic-based version that takes between 20-30 minutes to complete. There may be clinical scenarios where the PDT-Com may not be suitable if speed of assessment is important.

As already stated in Chapter 3, a further limitation of the PDT-Com assessment tool is the requirement of specialist equipment to measure muscle force values and a computer software programme to analyse the data. This may be problematic where financial resources are limited insofar as it brings a cost disadvantage compared to other assessments tools. Another important limitation is the requirement of a web-based computer software programme that analyses and produces the PDT-Com output graph and composite scores.

11.3.4 Obtaining Reference Values Using HHD

A study using a larger and more diverse sample of older adults, using the PDT-Com assessment protocol, could be used to create a database of reference values. This would allow further investigation stratified by age category (60-65; 66-70; 71-75 etc.), height, weight and activity levels.

11.3.5 PDT-Com Intra- and Inter-rater Reliability

Chapter 9 presented two studies examining PDT-Com reliability that have several limitations which should be considered. Firstly, the test-retest reliability measures were obtained in a single session with a short re-test period to reduce possible fatigue bias. However, the tests may have caused muscle fatigue both in the subjects and in the raters. As a result, these results may not necessarily be generalisable to re-testing over a longer and potentially more unstable periods.

A key limitation of the reliability studies in Chapter 9 are the small sample sizes. Although sample sizes are generally small in reliability studies due to practical and logistical constraints when measuring limb strength, a larger sample size would have allowed for more precision in the analyses (447).

Another limitation, and a component of the PDT-Com movement analysis which may contribute to score variability, is the scoring criteria itself. One of the limitations noted in the PDT-Com movement tests was a restriction in the range of scores. Specifically, based on the ordinal scoring criteria, no participants scored a 1 or 6 for the squat, 1, 2 or 6 for the lunge test, and no participant scored 5 or 6 for the SLSQ movement. This restriction in range might have reduced the reliability estimates in the movement scores, particularly for the lunge. Furthermore, several dysfunctions are less clearly defined than others and can either be interpreted differently or not observed. This is particularly the case for identifying ankle pronation when the participant's dysfunction is present but less obvious.

11.3.6 Randomised Feasibility Study

It was not possible within the constraints of this doctoral work to recruit a larger sample size for the feasibility study. As a result, it was not adequately powered to determine intervention effectiveness. In addition, the ability to apply the results of this study to the general older adult population is limited by the homogeneity of the sample. It was beyond the scope of this study to directly compare results with existing exercise intervention programmes such as the Otago and FaME. A further limitation was that only high-functioning older adults were invited to participate in the experimental studies. Although these results are promising, this is only a feasibility study and as such underpowered. Therefore, results of this study must be interpreted with caution. Regardless of this, this work will be submitted for publication.

11.4 CLINICAL IMPLICATIONS AND RECOMMENDATIONS

Findings from the studies in this thesis have direct clinical implications that can be incorporated into the identification and management of fall risk in community-dwelling older adults. Firstly, if health professionals require a reliable and valid measure of physical function that can direct exercise intervention then the PDT-Com can be recommended.

Secondly, a fundamental criterion is that the PDT-Com provides continuously scored measurements (quantitative) rather than dichotomous or graded scores. As a result, measurements can be analysed using regression techniques and discriminant analysis. In addition, standardisation of the PDT-Com reduces subjectivity by the health professional administering the test. Continuously scored measurements also avoid ceiling and floor effects, which can be prevalent in other measurements of lower-extremity muscle strength and balance ability.

Thirdly, results of feasibility work presented in Chapter 10 support the use of this new assessment tool to direct an individually prescribed corrective exercise programme. The study results suggested a three-month exercise intervention was a safe, feasible and acceptable option in community-dwelling older adults. A key finding was the perfect score on the BBS by all subjects, coupled with comparatively high performance in the TUG and 30sCRT that indicated these assessments were not be suitable for assessing higher-functioning community-dwelling older adults. This finding suggests that the PDT-Com assessment may be a more suitable option over current assessment tools.

11.5 FURTHER RESEARCH AND CONSIDERATIONS

Additional studies are required to develop the PDT-Com to be able to discriminate between older adult fallers and non-fallers. A series of large-scale prospective studies using the PDT-Com assessment tool could help determine which PDT-Com composite scores are associated with a fall, multiple fall and/or injurious falls. More studies will be needed to establish additional psychometric properties of this new assessment tool. For example, it will be important to compare the PDT-Com with other scales or tests currently used in fall prevention research, as well as its predictive validity across several different domains of fall risk.

The development of a PDT-Com short- or field-based version is warranted that may produce several benefits. Firstly, the time and cost implications are negated. Secondly, the short version can be used more frequently and be used to measure progress during and after an exercise intervention.

The PDT-Com provides valuable information about how an individual performs transitional movements. Thus, how an individual performance in the PDT-Com will provide great insight into their functional strength and exercise tolerance levels.

Although the raters in this thesis were clinically experienced and well trained in the use of hand-held dynamometry, future research should address the degree to which lesser experienced raters reliably administer the test. It will also be important that studies that set out to establish the minimum training time required to administer a reliably test score. Furthermore, future research may evaluate whether all PDT-Com test items are required. The fact that test-re-test reliability of plantar flexion muscle action force was unreliable (ICC = .44, 95%CI = -.11 - .83) suggests that this measurement could be omitted.

To provide the strongest evidence for the use of a physiological approach to preventing falls in community-dwelling older adults, more high-quality randomised controlled clinical trials testing suitable interventions will be required. Specifically, this thesis highlighted the paucity of research comparing exercise interventions to prevent falling in older adults. Comparisons are also required to investigate and compare the relative effect of different interventions, as well as applied to different clinical settings e.g. primary care. The impact of those interventions and the possible adaptations they provide needs to be examined both in the short- and the long-term.

Future research implications have been discussed in each of the chapters and questions generated by work within this thesis have been discussed. The following questions can be used to direct future research studies:

- Can a fall risk assessment tool's accuracy be enhanced when used in combination with the PDT-Com?
- What are the differences in PDT-Com scores between non-fallers, multiple fallers and the unsteady?
- What is the relationship between PDT-Com scores and injurious falls?
- Is there a relationship between movement competency and fall risk and/or injurious falls?

11.6 CHAPTER SUMMARY

This chapter aimed to draw together the findings from the previous nine chapters and provide an overall summary for this doctoral work. Key messages, limitations, clinical implications and future research recommendations have been provided. The next stage of this work is to submit aspects of the completed research for presentation at scientific conferences and for publication in peer-reviewed journals specialising in geriatric medicine, falls prevention and sports science.

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12 APPENDICES

12.1 APPENDIX A – SEARCH STRATEGY (CHAPTER 7)

Searches were adapted to all databases.

1. exp accidental falls/
2. (falls or faller$).tw.
3. 1 or 2
4. exp aged/
5. (older or senior$ or elderly).tw.
6. 4 or 5
7. (old people or geriatric$).mp.
8. 6 or 7
9. (risk assessment or assessment tool).mp.
10. (POMA or B-POMA or performance orient$ mobility).mp.
11. STRATIFY.mp.
12. FRHOP.mp.
13. falls risk for hospitalised older people.mp.
14. (ppa or physiological profile assessment).mp.
15. (FSST or four square step test).mp.
16. Functional reach test.mp.
17. ((timed up and go) or TUG or TUGT or timed up & go).mp.
18. berg balance scale.mp.
19. dynamic gait index.mp.
20. (((one leg or one-leg) and (stand or stance)) or OLST).mp.
21. (Peter James Centre Fall Risk assessment tool or PJC-FRAT).mp.
22. (falls risk assessment tool or FRAT).mp.
23. activities-specific balance confidence.mp.
24. (downton fall risk index or downton index).mp. [mp=title, abstract, original title, name of substance word, subject heading word, protocol supplementary concept, rare disease supplementary concept, unique identifier]
25. ((home falls and accidents screening tool) or HOME FAST).mp.
26. (activities of daily vision scale or ADVS).mp.
27. morse fall scale.mp.
28. elderly fall screening test.mp.
29. (Tinetti balance and (score or scale)).mp.
30. 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28 or 29
31. (specificity or screening or false positive or false negative or accuracy or predictive value$ or reference value$ or ROC or likelihood ratio).mp.
32. 3 and 8 and 9 and 30

12.2 APPENDIX B – ASSESSMENT TOOLS AND REFERENCES

Assessment tools & references that met inclusion criteria

Assessment Tool	Reference/s
Performance Oriented Mobility Assessment (POMA)	Tinetti *et al* (1986)(395) & Tinetti *et al* (1988)(71)
Functional Gait Assessment (FGA)	Wrisley *et al* (2004)(397)
Timed up & Go (TUG)	Podsiadlo & Richardson (1991)(331) & Bohannon (2006)(342)
Lateral Reach (LR)	Brauer *et al* (1999)(398) & Brauer *et al* (2000)(399)
Demura's Fall Risk Assessment (DFRA)	Demura *et al* (2011)(28) & Demura *et al* (2011)(27)
Fall Risk for Older People in the Community (FROP-Com)	Russell *et al* (2008)(402) & Russell *et al* (2008)(401)
Berg Balance Scale (BBS)	Berg (1989)(330); Berg (1989)(524) & Berg *et al* (1992)(414)
Functional Reach Test (FR)	Duncan *et al* (1990)(405) & Brauer *et al* (2000)(399)
Balance Evaluation Systems Test (BESTest)	Horak *et al* (2009)(406)
Elderly Fall Screening Test (EFST)	Cwikel *et al* (1998)(407)
Four Square Step Test (FSST)	Dite & Temple (2002)(408)
Rapid Step Test (RST)	Medell & Alexander (2000)(409)
Physiological Profile Assessment (PPA)	Lord *et al* (1994)(307) & Lord *et al* (2005)(61)
Fullerton Advanced Balance Scale (FAB)	Rose *et al* (2006)(411) & Hernandez & Rose (2008)(410)
Clinical Test for Sensory Interaction & Balance (CTSIB)	Boulgarides *et al* (2003)(24)
Fast Evaluation of Mobility Balance & Fear (FEMBAF)	Di Fabio & Seay (1997) (412)

12.3 APPENDIX C – ETHICAL APPROVAL FORM FOR PDT-COM IRR STUDY (BSREC)

16th June 2014

Warwick
Medical School

PRIVATE
Spencer Brown
Peak Performance (Unit 6)
Eastlands Court
St Peter's Road
Rugby
CV21 3QP

Dear Spencer

Study Title and BSREC Reference: *Normative Values or Lower-extremity Muscle Strength & Inter-rater Reliability of the Performance Deficit Test for Community-dwelling Elderly People (PDT-Com)* **REGO-2014-708**

Thank you for submitting your revisions to the above-named project to the University of Warwick's Biomedical and Scientific Research Ethics Sub-Committee for approval.

I am pleased to confirm that approval is granted and your study may commence.

Please keep a copy of the signed version of this letter with your study documentation.

Yours sincerely

[redacted]

David Davies
Chair
Biomedical and Scientific
Research Ethics Sub-Committee

Biomedical and Scientific Research Ethics Sub-Committee
A010 Medical School Building
Warwick Medical School,
Coventry, CV4 7AL.
Tel: 02476-151875
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THE UNIVERSITY OF WARWICK

12.4 APPENDIX D – IRR STUDY - PARTICIPANT CONSENT FORM

THE UNIVERSITY OF WARWICK

CONSENT FORM

(Biomedical and Scientific Research Ethics Committee) Study Number: 1157654

Patient Identification Number for this study:

Title of Project: Inter-rater Reliability of the Functional Assessment Screening Test for Community-dwelling Elderly People (PDT-Com)

Name of Researcher(s): Spencer Brown (Supervisors – Prof Simon Gates & Dr Julie Bruce)

Please initial all boxes

1. I confirm that I have read and understand the information sheet dated **[DATE]** (version **[VERSION NUMBER]**) for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my medical, social care or education* (**delete as appropriate*) or legal rights being affected.

3. I understand that relevant sections of my medical notes and data collected during the study, may be looked at by individuals from The University of Warwick, from regulatory authorities (or from a relevant NHS Trust* **delete if inapplicable*), where it is relevant to my taking part in this research. I give permission for these individuals to have access to my records.

4. I agree to my GP being informed of my participation in the study.* *(*delete if inapplicable)*

5. I agree to take part in the above study.

Name of Participant	Date	Signature
Name of Person taking consent	Date	Signature

12.5 APPENDIX E – PDT-COM TRAINING MANUAL

PDT-Com Training Manual - Movement Testing

Equipment required:

- Measuring Tape
- One-inch tape (T-shape floor markings)
- HD camera (optional)

Mark out a T-shape on the floor with each line of tape measuring approximately 75cm. Subjects perform all movement tests without wearing any footwear.

Scoring:

The subject is asked to repeat each exercise a specified number of times and a score is recorded based on the type of movement dysfunctions observed by the rater. All movements are scored on an ordinal scale. A dysfunctional movement can be identified either bilaterally or unilaterally, and they apply to all three movements in the test battery.

For the 'Squat' exercise they are as follows:

- ankle pronation (inward movement of medial malleoli)
- knee valgus (foot/knee alignment)
- lateral hip sway or abduction
- lumbar/thoracic flexion (rounding)
- poor sagittal trunk alignment (with lower limb)
- decreased ROM* (posterior knee flexion angle >90 degrees)

Scoring Categories (Squat):

PDT Scoring Criteria - Squats			
Rear View			
Sagittal View			
Score	**1**	**2**	**3**
Criteria	• Ankle Pronation • Knee valgus • Lateral shift • Knee flexion <90 degrees • Lumbar/thoracic flexion • Poor sagittal trunk alignment	• Ankle pronation • Knee valgus • Knee Flexion <90 degrees + • Any other observed dysfunctions	• Ankle pronation • Knee valgus + • Any other observed dysfunction
Rear View			
Sagittal View			
Score	**4**	**5**	**6**
Criteria	• Ankle pronation OR • Knee valgus + • Any other observed dysfunction	• Any observed dysfunction (x 1)	• No observed dysfunctions

For the ‘Lunge’ exercise they are as follows:

- ankle pronation (inward movement of medial malleoli)
- lateral hip sway or abduction (hip/knee alignment)
- knee valgus (foot/knee alignment)
- poor sagittal trunk alignment (with lower limb)
- decreased ROM* (posterior knee flexion angle >90 degrees)
- poor frontal trunk alignment (lateral torso flexion)

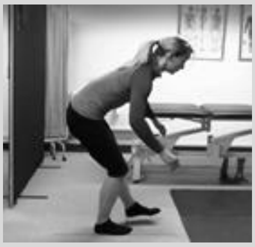
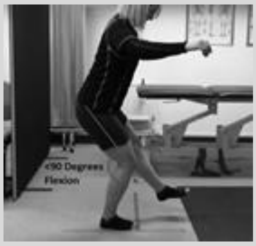
Scoring Categories (Lunge):

PDT Scoring Criteria - Lunge			
Frontal View			
Sagittal View			
Score	**1**	**2**	**3**
Criteria	• Ankle Pronation • Lateral hip shift • Knee valgus • Poor sagittal trunk alignment • Front knee flexion <90 degrees • Poor frontal trunk alignment	• Ankle pronation • Lateral Hip Shift • Knee Flexion <90 degrees + • Any other observed dysfunctions	• Ankle pronation • Lateral hip shift + • Any other observed dysfunction
Frontal View			
Sagittal View			
Score	**4**	**5**	**6**
Criteria	• Ankle pronation OR • Lateral Hip Shift + • Any other observed dysfunction	• Any observed dysfunction (x 1)	• No observed dysfunctions

For the ‘single leg squat’ exercise they are as follows:

- ankle pronation (inward movement of medial malleoli)
- knee valgus (foot/knee alignment)
- Loss of balance
- poor sagittal trunk alignment (with lower limb)
- decreased ROM* (posterior knee flexion angle >90 degrees)
- poor frontal trunk alignment (lateral torso flexion)

Scoring Categories (Single Leg Squat):

<table>
<tr><th colspan="4">PDT Scoring Criteria - SLSQ</th></tr>
<tr><td>Frontal View</td><td></td><td></td><td></td></tr>
<tr><td>Sagittal View</td><td></td><td></td><td>
</td></tr>
<tr><td>Score</td><td>1</td><td>2</td><td>3</td></tr>
<tr><td>Criteria</td><td>• Ankle Pronation
• Knee valgus
• Loss of balance
• Poor sagittal trunk alignment
• Knee flexion <90 degrees
• Poor frontal plane trunk alignment</td><td>• Ankle pronation
• Knee valgus
• Loss of balance
+
• Any other observed dysfunctions</td><td>• Ankle pronation
• Knee valgus
+
• Any other observed dysfunctions</td></tr>
<tr><td>Frontal View</td><td></td><td></td><td></td></tr>
<tr><td>Sagittal View</td><td></td><td>
</td><td></td></tr>
<tr><td>Score</td><td>4</td><td>5</td><td>6</td></tr>
<tr><td>Criteria</td><td>• Ankle pronation
OR
• Knee valgus
+
• Any other observed dysfunctions</td><td>• Any observed dysfunction (x 1)</td><td>• No observed dysfunctions</td></tr>
</table>

* ROM = range of movement

The Squat

Description: The squat is a fundamental human movement that is required for many activities of daily living. The squat is a compound movement which challenges muscle and joint symmetry of both the upper and lower-body. This test will give a clear indication of the subject's ability to flex at the ankle, knee and hip in a co-ordinated and controlled show of strength and stability. Having the arms crossed in front of the body enables the therapist to assess bilateral symmetry, and the ability to control the trunk through observing forward lean and/or lateral flexion.

Tester notes: Participants may lose balance so be ready to guard against this. If subjects report pain during the movement immediately stop the test and record a zero score.

Start Position:

- Instruct the subject to place their feet shoulder width apart with their toes slightly turned out (approximately 10 degrees external rotation). Toes should be in line with the tape.
- Instruct the subject to cross their arms over in front of their body with arms parallel to the floor (shoulder at 90-degree forward flexion).
- Execution:
- Instruct the subject to descend towards the floor three times, bending at the ankle, knee and hip.
- The subject should descend as far as comfortable or until the top of the thigh is parallel to the floor (approximately 70-80-degree posterior knee flexion angle).
- Demonstrate the movement once prior to the subject completing the test.

- The subject should complete three squats facing the rater, three at 900 to the rater, and another three squats facing away from the rater. Subjects should line up their heels with the tape when facing away from the rater.

Special Instructions:

Cue the subject prior to the test to keep their heels in contact with the floor and to maintain their arms in the start position i.e. parallel to the floor. If necessary, repeat the verbal cue once more.

Participant Instructions:

'We are going to do three movements, and the first one is called a squat. This is what I would like you to do:'

Verbally cue the exercise and demonstrate the squat movement according to the instructions above.

'I would like you to descend towards the floor, bending at the knee and hip, as far as comfortably possible, or until the top of your thighs are parallel to the floor.'

If necessary, cue the subject that they have reached the required depth in the squat i.e. top of the thighs parallel to the floor.

'Make sure your heels remain in contact with the floor and your arms remain crossed in front of your body, parallel to the ground.'

'I would like you to repeat this movement three times.'

'Now I would like you to turn 90 degrees to your left, line up your toes with the tape as before, and complete three more squats.'

'Now I would like you to turn another 90 degrees to your left so that you are facing away from me. And on this occasion, line up your heels with the tape and complete three more squats.'

PDT Scoring Criteria - Squats			
Rear View			
Sagittal View			
Score	**1**	**2**	**3**
Criteria	• Ankle Pronation • Knee valgus • Lateral shift • Knee flexion <90 degrees • Lumbar/thoracic flexion • Poor sagittal trunk alignment	• Ankle pronation • Knee valgus • Knee Flexion <90 degrees + • Any other observed dysfunctions	• Ankle pronation • Knee valgus + • Any other observed dysfunction
Rear View			
Sagittal View			
Score	**4**	**5**	**6**
Criteria	• Ankle pronation OR • Knee valgus + • Any other observed dysfunction	• Any observed dysfunction (x 1)	• No observed dysfunctions

The Lunge

Description: The lunge test places the subject's body in a position that challenges unilateral deceleration, rotation and balance. It is a prime illustration of the fundamentals of walking and running mechanics, in particular the ability to resist rotation to control the body and maintain proper alignment. The lunge test specifically assesses ankle and knee mobility and stability, ankle, knee and hip alignment, flexibility of the lower-extremity muscles and torso control.

Tester notes: Participants may lose balance so be ready to guard against this. If subjects report pain during the movement, or repeatedly fail to adopt the starting position due to poor balance, immediately stop the test and record a zero score.

Start Position:

- Instruct the subject to stand hip width apart, facing the rater with toes lined up with the tape.
- Take a measurement of the distance from the floor to mid patellar. Measure the same distance from the heel of one foot rearwards, and instruct the subject to step back with the other foot to this distance, placing only the ball of the foot in contact with the floor (maintaining a hip width stance).
- Instruct the subject to cross their arms over in front of body with arms parallel to the floor (shoulder at 90degree forward flexion).
- Execution:
- Instruct the subject to descend towards the floor three times, bending at the ankle, knee and hip.

- The subject should descend as far as comfortable or until the top of the thigh is parallel to the floor (approximately 70-80-degree knee flexion).
- Demonstrate the movement once prior to the subject completing the test.
- The subject should complete three lunges on each leg facing the rater. The subject then completes another set of lunges on each leg at 90 degrees to the rater. Each set of three is alternated between the left and right leg to minimise fatigue.

Special Instructions:

Cue the subject prior to the test to keep the heel of the front foot in contact with the floor, and to remain on their toes on the rear foot. Cue the subject to maintain their arms in the start position i.e. parallel to the floor and to maintain an upright torso throughout. If necessary, repeat the verbal cues once more.

Participant Instructions:

'The next movement is called a lunge, and this is what I would like you to do:'

Verbally cue the exercise and demonstrate the lunge movement according to the instructions above.

'I would like you to descend towards the floor, bending at the ankle, knee and hip, as far as comfortably possible, or until the front leg thigh is parallel to the floor.'

If necessary, cue the subject that they have reached the required depth in the lunge i.e. top of the thighs parallel to the floor.

'Make sure the heel of the front foot remains in contact with the floor and that you remain on the toes of the rear foot. Your arms should remain crossed in front of your body, parallel to the ground.'

'I would like you to repeat this movement three times on each leg.'

'Now I would like you to turn 90 degrees to your left and complete three more lunges on each leg.'

PDT Scoring Criteria - Lunge			
Frontal View			
Sagittal View			
Score	**1**	**2**	**3**
Criteria	• Ankle Pronation • Lateral hip shift • Knee valgus • Poor sagittal trunk alignment • Front knee flexion <90 degrees • Poor frontal trunk alignment	• Ankle pronation • Lateral Hip Shift • Knee Flexion <90 degrees + • Any other observed dysfunctions	• Ankle pronation • Lateral hip shift + • Any other observed dysfunction
Frontal View			
Sagittal View			
Score	**4**	**5**	**6**
Criteria	• Ankle pronation OR • Lateral Hip Shift + • Any other observed dysfunction	• Any observed dysfunction (x 1)	• No observed dysfunctions

The Single Leg Squat

Description: The single leg squat is the most advanced movement in the PDT-Com test battery. It is similar in many ways to the lunge but places greater stresses through the knee and hip complex. The unilateral nature of this movement requires the subject to generate greater amounts of lower-extremity muscle force to resist rotation, maintain proper alignment and remain stable in a single leg stance. In particular, it highlights left/right functional limitations and imbalances which can be a precursor to more serious musculoskeletal dysfunctions.

Tester notes: Participants may lose balance so be ready to guard against this. If subjects report pain during the movement, or repeatedly fail to adopt the starting position due to poor balance, immediately stop the test and record a zero score.

Start Position:

- Instruct the subject to stand hip width apart, facing the rater with toes lined up with the tape.
- Instruct the subject to stand on one leg. Line up the toes on the tape so that the foot is pointing straight ahead. The unsupported leg should be placed out in front of the body.
- Instruct the subject to use their arms for balance.
- Execution:
- Instruct the subject to descend towards the floor three times, bending at the ankle, knee and hip.
- The subject should descend as far as comfortable or until the top of the thigh is parallel to the floor (approximately 70-80 degree knee flexion).

- Demonstrate the movement once prior to the subject completing the test.
- The subject should complete three single leg squats on each leg facing the rater. The subject then completes another set of single leg squats on each leg at 900 to the rater, lining up the toes with the tape as before. Each set of three is alternated between the left and right leg to minimise fatigue.

Special Instructions:

Cue the subject prior to the test to keep their heel in contact with the floor. If necessary, repeat the verbal cue once more.

Participant Instructions:

'The next movement is called a single leg squat, and this is what I would like you to do:'

Verbally cue the exercise and demonstrate the single leg squat movement according to the instructions above.

'I would like you to descend towards the floor, bending at the knee and hip, as far as comfortably possible, or until the top of your thigh is parallel to the floor.'

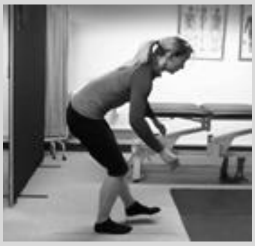
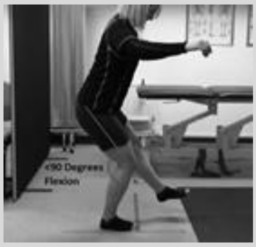
If necessary, cue the subject that they have reached the required depth in the single leg squat i.e. 90 degree knee flexion angle.

'Make sure the heel remains in contact with the floor.'

'I would like you to repeat this movement three times on each leg.'

'Now I would like you to turn 90 degrees to your left and complete three more single leg squats on each leg.'

PDT Scoring Criteria - SLSQ

Frontal View			
Sagittal View			
Score	**1**	**2**	**3**
Criteria	• Ankle Pronation • Knee valgus • Loss of balance • Poor sagittal trunk alignment • Knee flexion <90 degrees • Poor frontal plane trunk alignment	• Ankle pronation • Knee valgus • Loss of balance + • Any other observed dysfunctions	• Ankle pronation • Knee valgus + • Any other observed dysfunctions
Frontal View			
Sagittal View			
Score	**4**	**5**	**6**
Criteria	• Ankle pronation OR • Knee valgus + • Any other observed dysfunctions	• Any observed dysfunction (x 1)	• No observed dysfunctions

12.6 APPENDIX F – TIMED UP AND GO TEST STADARDISED PROCEDURES

The TUG test is a measure of functional mobility among older adults, and has been reported to have high reliability (ICC = .98) in older adults (331). Participants were instructed to sit on a chair (height of 46cm and with arm rest height of 65cm) that was placed against the wall. Participants were instructed to stand, walk at their normal pace on a three-meter pathway, turn at the end-point mark, walk back on the determined pathway, and resit on the chair. Time in seconds were recorded when the buttock of the participants touched the chair on completion. Participants were allowed a trial session for familiarisation, and three experimental sessions were performed with an adequate rest between each test. The mean of the three scores is taken as the TUG test score.

12.7 APPENDIX G – BERG BALANCE SCALE

The Berg Balance Scale (BBS) is one of the most widely used and validated instruments for assessing balance performance in community-dwelling older people. The BBS, created in 1989, contains 14 static and dynamic activities related to everyday living (330). The BBS assesses balance and risk for falls through direct observation of the participant's performance by trained health care professionals in a variety of settings. The BBS tasks progress in challenges: from sitting to standing, standing with narrow base of support, and finally to tandem and single-leg stance. Scoring is on a 5-point ordinal scale with 0 indicating an inability to complete the task and 4 as independent with completing the task. The maximum score of 56 indicates good balance. The scale takes approximately 10 to 20 minutes to complete requiring minimal equipment (chair, stopwatch, ruler, and step) and minimal space.

12.8 APPENDIX H – 30 SECOND CHAIR RISE TEST

The 30-second Chair Rise Test is administered using a chair without arms, with a seat height of 17 inches (43.2cm). The chair is placed against a wall to prevent it from moving. The participant is seated in the middle of the chair, back straight; feet approximately shoulder width apart and placed on the floor at an angle slightly back from the knees, with one foot slightly in front of the other to help maintain balance. Arms are crossed at the wrists and held against the chest. If a patient must use their arms to complete the test they are scored a zero. On a verbal signal, the participant rises to a full stand (body erect and straight) and then returns to the initial seated position. The participant is encouraged to complete as many stands as possible within 30 seconds. The participant is instructed to fully sit between each stand. The rater records the number of correct stands in 30 seconds (more than halfway up at the end of the 30 seconds counts as a full stand).

12.9 APPENDIX I - PATIENT SATISFACTION QUESTIONNAIRE

Please help us improve our programme by answering some questions about the service you have received. We are interested in your honest opinion, whether positive or negative. Please answer all of the questions. We also welcome your comments and suggestions. Thank you very much; we really appreciate your help.

PLEASE CHECK THE BOX BELOW FOR THE RESPONSE YOU WANT TO MAKE TO EACH QUESTION.

<u>PART 1 - Group Exercise</u>

1. How would you rate the therapist's ability to explain what you will be doing during each exercise session?

☐	☐	☐	☐	☐
Poor	Fair	Good	Very Good	Excellent

2. How would you rate the ability of the therapist to put you at ease?

☐	☐	☐	☐	☐
Poor	Fair	Good	Very Good	Excellent

3. How would you rate the extent to which the exercises were adapted to your needs?

☐	☐	☐	☐	☐
Poor	Fair	Good	Very Good	Excellent

4. How would you rate the comfort of the room where the exercise session took place?

☐ Poor	☐ Fair	☐ Good	☐ Very Good	☐ Excellent

5. How would you rate the quality of information you received during your group sessions?

☐ Poor	☐ Fair	☐ Good	☐ Very Good	☐ Excellent

6. How would you rate the ease of access to the group exercise facility?

☐ Poor	☐ Fair	☐ Good	☐ Very Good	☐ Excellent

7. How would you rate the overall quality of the group exercise sessions you received?

☐ Poor	☐ Fair	☐ Good	☐ Very Good	☐ Excellent

PART 2 – Home Exercises

8. The directions in the instruction booklet were clear?

☐	☐	☐	☐	☐
Strongly disagree	Disagree	Agree	Moderately agree	Strongly agree

9. The exercises were worth my time to do?

☐	☐	☐	☐	☐
Strongly disagree	Disagree	Agree	Moderately agree	Strongly agree

10. I was able to do the exercises without much difficulty?

☐	☐	☐	☐	☐
Strongly disagree	Disagree	Agree	Moderately agree	Strongly agree

11. I received the guidance I needed from the instruction booklet?

☐	☐	☐	☐	☐
Strongly disagree	Disagree	Agree	Moderately agree	Strongly agree

12. How would you rate the quality of the service you received?

☐	☐	☐	☐	☐
Poor	Fair	Good	Very Good	Excellent

13. If a friend were in need of similar help, would you recommend our program to him or her?

☐	☐	☐	☐	☐
Certainly not	Probably not	Not sure	Yes, probably	Yes, certainly

14. Do you have any comments about the exercise programme or study overall?

12.10 APPENDIX J - SELF-REPORT QUESTIONNAIRE FOR TRIAL INCLUSION

Pre-Trial Questionnaire

(Biomedical and Scientific Research Ethics Committee) Study Number:

Patient Identification Number for this study:

Title of Project: A Pilot Randomised Controlled Trial Comparing an Exercise Programme to Improve Physical Function versus Usual Care in Community-dwelling adults Aged over 60 Years

Name of Researcher(s): Spencer Brown; Prof. Simon Gates & Prof Julie Bruce (Supervisors)

Gender: **M / F**

Age: _______Height (cm): _______Weight (kg): _______ Dominant Side (lower body): **L / R**

Do you live independently in the community? **YES / NO**

Are you physically able to participate in a small group exercise class **YES / NO**

Are you receiving more than 2 sessions of physio a week? **YES / NO**

Please indicate if you have the following (Please cross (X) one):

Severe visual impairment………………………………………………………………………………… ☐

Psychiatric conditions or cognitive impairment…………………………………………………… ☐

Heart disease or angina……………………………………………………………………………………… ☐

Neurological disease or impairment…………………………………………………………………… ☐

Acute rheumatoid arthritis………………………………………………………………………………… ☐

Less than 12 months post-surgery of ankle, knee or hip joint…………………………………… ☐

12.11 APPENDIX K - ADVERSE EVENTS NOTIFICATION FORM

Adverse Event Notification Form

Participant Trial ID: ☐☐☐☐ Participant Initials: ☐☐

Site: ________

11.2 ADVERSE EVENT DETAILS

1. Date of Adverse Event: d d - m o n - y y y y

2. Circumstance of Adverse Event:
   - During group exercise session ☐
   - During unsupervised exercise ☐
   - Other *(please specify)*: ☐

3. Details of Adverse Event: *(Please provide full details below)*

Form completed by (print name): ________ *(Please note: your name must be on the trial delegation log)*

Signature: ________ Date signed: d d - m o n - y y y y

TRIAL OFFICE USE ONLY

Date AE reviewed: d d - m o n - y y y y

Is an SAE Form required? No ☐ Yes ☐ → Date requested: d d - m o n - y y y y

Signature: ________ Date: d d - m o n - y y y y

Adverse Event Notification Form Version 1.1; Feb 2017

12.12 APPENDIX L – SERIOUS ADVERSE EVENTS FORM

Serious Adverse Event Form—Initial

Participant Trial ID: ☐☐☐☐ **Participant Initials:** ☐☐

Site: ____________________

For Trial Office Use Only

SAE Reference Number: ☐

Please fax immediately to WMS on 02476 150549

8.1 EVENT TYPE: *(please confirm 'Yes' or 'No' for each category)*

	No	Yes
1. Death	☐	☐
2. Life-threatening	☐	☐
3. Hospitalisation or prolongation of existing hospitalisation	☐	☐
4. Persistent or significant disability/incapacity	☐	☐
5. Congenital anomaly/birth defect	☐	☐
6. Other reason *(please specify below)*	☐	☐

8.2 EVENT DETAILS:

1. Date event deemed serious: d d - m o n - y y y y

2. Details of Event:
Please include all **relevant** details of the event, any tests performed and associated results:

(Please continue on SAE Continuation Form as necessary)

Please add details of any **relevant** medical history, concomitant medication and associated dates of administration:

(Please continue on SAE Continuation Form as necessary)

8.3 SEVERITY ASSESSMENT:

☐ Mild—Does not interfere with patient's usual functioning

☐ Moderate—Interferes to some extent with patient's usual functioning

☐ Severe—Interferes significantly with patient's usual functioning

☐ Fatal/Life threatening— Causes death or risk of death, organ damage or disability

Serious Adverse Event Initial Form. Version 1.0; Feb 2017

SAE EVALUATION FORM *(for Trial Office use only)*

Date adverse event information was passed to CI: d d - m o n - y y y y **SAE Reference Number:** ☐

Were further investigations requested by CI? No ☐ Yes ☐ → **Date further investigations carried out:** d d - m o n - y y y y

Details of investigations: ☐

Date findings of further investigations passed to CI: d d - m o n - y y y y

Is the event related to the intervention? → No ☐

↓ Yes ☐

Is it Unexpected? → No ☐

↓ Yes ☐

Date report sent to MREC / sponsor (within 15 days of sponsor first aware of event): d d - m o n - y y y y

Chief Investigators signature: ______________________ **Date:** d d - m o n - y y y y

12.13 APPENDIX M – ETHICAL APPROVAL FORM FOR RANDOMISED FEASIBILITY STUDY (BSREC)

WARWICK
THE UNIVERSITY OF WARWICK

PRIVATE
Mr Spencer Brown
Warwick Medical School
University of Warwick
Coventry
CV4 7AL

24 February 2017

Dear Mr Brown

Study Title and BSREC Reference: *A comparison study of the Timed Up and o, Berg Balance Test, 10s Chair Stand Test and a Novel Physical Assessment on 3-month outcome measures* REGO-2016-1884

Thank you for submitting the revisions to the above-named study to the University of Warwick's Biomedical and Scientific Research Ethics Sub-Committee for approval.

I am pleased to confirm that approval is granted and that your study may commence.

In undertaking your study, you are required to comply with the University of Warwick's *Research Data Management Policy*, details of which may be found on the Research and Impact Services' webpages, under "Codes of Practice & Policies" » "Research Code of Practice" » "Data & Records" » "Research Data Management Policy", at:
http://www2.warwick.ac.uk/services/ris/research_integrity/code_of_practice_and_policies/research_code_of_practice/datacollection_retention/research_data_mgt_policy

You are also required to comply with the University of Warwick's *Information Classification and Handling Procedure*, details of which may be found on the University's Governance webpages, under "Governance" » "Information Security" » "Information Classification and Handling Procedure", at:
http://www2.warwick.ac.uk/services/gov/informationsecurity/handling.
Investigators should familiarise themselves with the classifications of information defined therein, and the requirements for the storage and transportation of information within the different classifications:

> *Information Classifications:*
> http://www2.warwick.ac.uk/services/gov/informationsecurity/handling/classifications
> *Handling Electronic Information:*
> http://www2.warwick.ac.uk/services/gov/informationsecurity/handling/electronic/
> *Handling Paper or other media*
> http://www2.warwick.ac.uk/services/gov/informationsecurity/handling/paper/.

Please also be aware that BSREC grants **ethical approval** for studies. **The seeking and obtaining of *all* other necessary approvals is the responsibility of the investigator.**

These other approvals may include, but are not limited to:

www.warwick.ac.uk

1. Any necessary agreements, approvals, or permissions required in order to comply with the University of Warwick's Financial Regulations and Procedures.
2. Any necessary approval or permission required in order to comply with the University of Warwick's Quality Management System and Standard Operating Procedures for the governance, acquisition, storage, use, and disposal of human samples for research.
3. All relevant University, Faculty, and Divisional/Departmental approvals, if an employee or student of the University of Warwick.
4. Approval from the applicant's academic supervisor and course/module leader (as appropriate), if a student of the University of Warwick.
5. NHS Trust R&D Management Approval, for research studies undertaken in NHS Trusts.
6. NHS Trust Clinical Audit Approval, for clinical audit studies undertaken in NHS Trusts.
7. Approval from Departmental or Divisional Heads, as required under local procedures, within Health and Social Care organisations hosting the study.
8. Local ethical approval for studies undertaken overseas, or in other HE institutions in the UK.
9. Approval from Heads (or delegates thereof) of UK Medical Schools, for studies involving medical students as participants.
10. Permission from Warwick Medical School to access medical students or medical student data for research or evaluation purposes.
11. NHS Trust Caldicott Guardian Approval, for studies where identifiable data is being transferred outside of the direct clinical care team. Individual NHS Trust procedures vary in their implementation of Caldicott guidance, and local guidance must be sought.
12. Any other approval required by the institution hosting the study, or by the applicant's employer.

There is no requirement to supply documentary evidence of any of the above to BSREC, but applicants should hold such evidence in their Study Master File for University of Warwick auditing and monitoring purposes. You may be required to supply evidence of any necessary approvals to other University functions, e.g. The Finance Office, Research & Impact Services (RIS), or your Department/School.

May I take this opportunity to wish you success with your study, and to remind you that any Substantial Amendments to your study require approval from BSREC before they may be implemented.

Yours sincerely

pp. [redacted]

Professor John Davey
Chair
Biomedical and Scientific
Research Ethics Sub-Committee

Biomedical and Scientific
Research Ethics Sub-Committee
Research & Impact Services
University of Warwick
Coventry, CV4 8UW.
E: BSREC@Warwick.ac.uk

http://www2.warwick.ac.uk/services/ris/research_integrity/researchethicscommittees/biomed

12.14 APPENDIX N - RANDOMISED FEASIBILITY STUDY - PARTICIPANT CONSENT FORM

THE UNIVERSITY OF WARWICK

CONSENT FORM

(Biomedical and Scientific Research Ethics Committee) Study Number: REGO-2014-708

Patient Identification Number for this study:

Title of Project: Physical Function Assessment (normative values, Section One)

Name of Researcher(s): Spencer Brown (Student No. 1157654); Prof. Simon Gates & Prof. Julie Bruce (Supervisors)

Please initial all boxes

I confirm that I have read and understand the information sheet dated **May 2014**

(v2.0 for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

1. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my medical or legal rights being affected.
2. I agree to my GP being informed of my participation in the study.
3. I agree to take part in the above study.

Name of Participant	Date	Signature
Name of Person Taking Consent	Date	Signature

12.15 APPENDIX O – PILOT RANDOMISED CONTROLLED TRIAL - PARTICIPANT INFORMATION

WARWICK
THE UNIVERSITY OF WARWICK

Study Title: **A Pilot Randomised Controlled Trial Comparing an Exercise Programme to Improve Physical Function versus Usual Care in Community-dwelling Adults Aged over 60 Years**

Investigator(s): **Spencer Brown, Simon Gates, Julie Bruce**

Introduction

You are invited to take part in a study. Before you decide, you need to understand why the study is being done and what it would involve for you. Please take the time to read the following information carefully. Talk to others about the study if you wish.

(Part 1 tells you the purpose of the study and what will happen to you if you take part. Part 2 gives you more detailed information about the conduct of the study)

Please ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

PART 1

What is the study about?

The aim of this research project is to compare the results of several physical assessments and to examine the effects and feasibility of a 3-month group and home exercise programme for community-dwelling older adults. This study will increase our understanding and awareness of physical problems that are associated with falling in community-dwelling older adults.

Do I have to take part?

It is entirely up to you to decide. We will describe the study and go through this information sheet, which we will give you to keep. If you choose to participate, we will ask you to sign a consent form to confirm that you have agreed to take part. You will be free to withdraw at any time, without giving a reason and this will not affect you or your circumstances in any way.

What will happen to me if I take part?

Your physical function will be assessed using four physical function tests. Firstly, your muscle strength in both legs will be tested by a therapist using a small hand-held machine. This will be followed by one of the therapists asking you to perform three repetitions of three basic movements (squat, lunge and single leg squat. Secondly, wearing regular footwear you will be asked to stand up, walk to a mark 3m (9.8 ft.) away, turn around and return to sit back in a chair. For this test, do the best you can and walk at your regular pace. Thirdly, you will be required to perform 14 simple balance related tasks ranging from standing up from a sitting position to standing on one foot. Fourthly, starting seated in a chair you will be asked to stand up completely so your hips and knees are fully extended, then completely sit back down, so that the bottom fully touches the seat. You will be required to repeat this movement for 30 seconds. For this test, do the best you can by going as fast as you can but don't push yourself to a point of overexertion or beyond what you think is safe for you.

The tests take approximately 60 minutes to complete and will take place at an injury rehabilitation clinic situated in Rugby Town, (Peak Performance, 40 Somers Road, Rugby, CV22 7DH) or The Percival Guildhouse, St Mathews Street, Rugby CV21 3BY.

You will be randomly selected into either an Exercise Group or a Control Group. All those selected for the Control Group can continue with their normal daily activities and exercise regimes. Those selected for the Exercise Group will be required to participate in one small group supervised exercise session each week for 12 weeks (maximum of six participants), and complete two home-based exercise sessions each week for 12 weeks. An instruction manual and training diary will be provided to assist with exercise completion and session adherence.

What are the possible disadvantages, side effects, risks, and/or discomforts of taking part in this study?

The main risks of taking part in this study are muscle strains, joint sprains, falling over and cardiovascular events, but previous research has shown these events to be extremely rare. Sometimes people experience mild soreness, particularly in the legs, for a few days following assessment. This is perfectly normal and there are no long-term negative effects. You can withdraw from the study at any time if you are in discomfort or you are worried that you might fall and injure yourself.

What are the possible benefits of taking part in this study?

This research may help improve the reduction of falling in the older population, as well as improving treatment for older people in the future. Once you finish the study we are more than happy to answer any questions you may have regarding the results of your functional assessment. The results of our study will be published in various journals and distributed at your primary healthcare provider. Any personal information will not be included and you will not be identified.

Expenses and payments

In the event you decide to take part there may be a small travel cost associated with getting to the clinic or Medical School (see addresses above). No expenses or payments will be made to any participants in this study.

What will happen when the study ends?

You will receive a copy of the assessment report and recommendations. Raw data will be stored electronically in a password protected area on a secure server. This data will be kept for 10 years. All hard copy data information will be destroyed once the study has ended.

Will my taking part be kept confidential?

Yes. We will follow strict ethical and legal practice and all information about you will be handled in confidence. Further details are included in Part 2.

What if there is a problem?

Any complaint about the way you have been dealt with during the study or any possible harm that you might suffer will be addressed. Detailed information is given in Part 2.

This concludes Part 1.

If the information in Part 1 has interested you and you are considering participation, please read the additional information in Part 2 before making any decision.

PART 2

Who is organising and funding the study?

This study is being conducted as part of my PhD research and is not funded by an external body or institution.

What will happen if I don't want to carry on being part of the study?

Participation in this study is entirely voluntary. Refusal to participate will not affect you in any way. If you decide to take part in the study, you will need to sign a consent form, which states that you have given your consent to participate.

If you agree to participate, you may nevertheless withdraw from the study at any time without affecting you in any way.

You have the right to withdraw from the study completely and decline any further contact by study staff after you withdraw.

What if there is a problem?

This study is covered by the University of Warwick's insurance and indemnity cover. If you have an issue, please contact the Chief Investigator of the study:

Spencer Brown

7 Farnborough Avenue

Rugby CV21 7EL

spencer@ppcoe.co.uk

01788 879805

Who should I contact if I wish to make a complaint?

Any complaint about the way you have been dealt with during the study or any possible harm you might have suffered will be addressed. Please address your complaint to the person below, who is a senior University of Warwick official entirely independent of this study:

Director of Delivery Assurance
Registrar's Office
University House
University of Warwick
Coventry
CV4 8UW
Complaints@Warwick.ac.uk
024 7657 4774

Will my taking part be kept confidential?

Any personal information (name, email addresses and phone numbers) collected will be kept confidential and any information that you provide us with (by completing any questionnaires or phone interviews) will only be used for this study.

What will happen to the results of the study?

The collected data will only be stored on the researcher's computer and we will only use your participant serial number. The collected information will only be used for this study and will not be used in any future research. Three supervisors of this project will have access to this data; however, they will not be able to identify you. It will not be possible to identify you from any published materials.

Who has reviewed the study?

This study has been reviewed and given favourable opinion by the University of Warwick's Biomedical and Scientific Research Ethics Committee (BSREC): REGO-2016-1884

What if I want more information about the study?

If you have any questions about any aspect of the study, or your participation in it, not answered by this participant information leaflet, please contact:

Spencer Brown at spencer@ppcoe.co.uk or on 01788 879805
Professor Simon Gates at simon.gates@warwick.ac.uk

Thank you for taking the time to read this participant information leaflet.

12.16 APPENDIX P – PDT-COM STANDARDISED PROCEDURE

PDT-Com Standardised Procedure v1.6

June 2015

Spencer Brown MSc BSc AST

Contents

List of Figures

List of Tables

1.0 Standard Procedure

1.1 Description and Scoring of the PDT-Com Lower-extremity Strength Tests

1.1.1 Hip Extension

The commonly used prone position (PP) (Figure 1 - left) has been shown to be unreliable in normal healthy subjects (212). However, an alternative prone standing position (PSP) (Figure 1 - right) is reported to be more reliable for measuring hip extensor strength (212) (525). The PDT-Com assessment protocol uses the PSP method (a 'make' test) to more reliably measure hip extension strength.

Figure 46 - *Testing positions for measuring hip extensor strength: the prone position – left; the prone standing position - right.*

The PSP is a 'make' test and requires the therapist to readjust the table so that the subject's trunk is supported by the table with the non-tested supporting leg in a comfortable and stable position (Figure 1 - right). The initial testing position of the leg is with the hip in approximately 45^{o} of flexion and the knee at full extension. The HHD is positioned on the posterior surface of the thigh proximal to the knee.

1.1.2 Hip Flexion

The hip flexor test is a 'make' test. For this test subjects are instructed to lie supine on a table; the therapist can adjust the height of the table to allow for maximum leverage. The initial testing position of the leg is the hip in 60^{o} of flexion with the knee relaxed and subject's foot in contact with the table (Figure 2). The subject is instructed to place arms across chest to prevent anchoring with the upper body. The position of the HHD is on the anterior surface of the thigh proximal to the knee.

Figure 47 - *Testing position for measuring hip flexor strength (make test).*

1.1.3 Hip Abduction

The hip abductors are tested on a table with the subject in a side-lying position (Figure 3). Subjects are instructed to lie on their side facing either away or towards the therapist; the therapist adjusts the height of the table to allow for maximum leverage.

Figure 48 - *Testing position for measuring hip abductor strength (break test).*

The initial testing position of the leg is in approximately 20° of hip abduction with the knee in full extension (Figure 3). The position of the HHD is on the lateral surface of the lower-limb approximately 10cm above the transverse line of the malleoli.

1.2 Hip Adduction

The hip adductors are tested using the side-lying 'break' test position. It requires the subject to adopt a side-lying position with the upper-most leg flexed at the hip and knee (Figure 4). Subjects are instructed to lie facing away from the therapist; the therapist adjusts the height of the table to allow for maximum leverage. The initial testing position of the leg is in approximately 15-20° of hip adduction with the knee in full extension. The position of the HHD is on the medial surface of the lower-limb approximately 10cm above the transverse line of the malleoli.

Figure 49 - *Testing position for measuring hip adductor strength. Side lying position (break test).*

1.2.1 Knee Flexion

The knee flexor muscles are tested in a prone position (Figure 5) using a 'make' test. The initial testing position of the subject is the knee in 60° of flexion, as measured by a goniometer, with the rater applying downwards pressure on the posterior surface of the distal femur (Figure 5). The position of the HHD is on the posterior surface of the lower-limb approximately 10cm above the transverse line of the malleoli.

Figure 50 - *Testing position for measuring knee flexor strength.*

1.2.2 Knee Extension

The knee extensor muscles are tested with the subject seated in a chair that is supported against a wall (Figure 6) using a ‘make’ test. The ‘make’ method for strength testing was performed rather than the ‘break’ method as it has been shown to have better reliability and provide more accurate measures (526, 527). A bolster is placed under the knee of the test leg so that the foot is not in contact with the floor. The therapist can kneel or sit to allow for maximum leverage. The initial testing position of the leg is 90^{o} of knee flexion as measured by goniometer (Figure 6). The position of the HHD is on the anterior surface of the lower-limb approximately 10cm above the transverse line of the malleoli.

Figure 51 - *Testing position for measuring knee extensor strength.*

1.2.3 Ankle Plantar Flexion

The ankle plantar flexors are tested using the ‘make’ test on a table with the subject’s back supported in an upright seated position. The initial testing position is to place the foot into 90^{o} dorsi flexion (neutral) with full knee extension (Figure 7). The position of the HHD is on the plantar aspect of the foot just proximal to the metatarsophalangeal joints.

As for the knee extensor test it is important that the therapist adopts a good body position to resist the subject’s force. The height of the table can also be adjusted by the therapist to allow for maximum resistance against the subject.

Figure 52 - *Testing position for measuring ankle plantar flexor strength.*

1.2.4 Ankle Dorsi Flexion

The ankle dorsi flexors are tested using the ‘make’ test on a table position with the subject’s back supported in an upright seated position. The initial testing position is the foot placed into full plantar flexion with a fully extended knee (Figure 8). The position of the HHD is on the anterior aspect of the foot just proximal to the metatarsophalangeal joints. The therapist can kneel or stand with the height of the table adjusted if required to allow for maximum resistance against the subject.

Figure 53 - *Testing position for measuring ankle dorsi flexors strength.*

1.2.5 Ankle Inversion

The ankle supinators are tested using the ‘make’ test on a table with the subject’s back supported in an upright seated position. Testing is performed with the foot plantar flexed and everted (turned outwards) with a fully extended knee. The therapist manually stabilises the subject’s calcaneus so that the supinators can be isolated by cupping the calcaneus with the opposite hand (Figure 9). The position of the HHD is on the medial aspect of the foot just proximal to the metatarsophalangeal joints. The height of the table can also be adjusted by the therapist to allow for maximum resistance against the subject.

Figure 54 - *Testing position for measuring ankle supinator strength.*

1.2.6 Ankle Pronation

The ankle pronators are tested using the 'make' test on a table with the subject's back supported in an upright seated position. Testing is performed with the foot fully plantar flexed and inverted with a fully extended knee. The test is facilitated using manual stabilisation in which the therapist cups the calcaneus with the opposite hand (Figure 10). The position of the HHD is on the lateral aspect of the foot just proximal to the metatarsophalangeal joints.

Figure 55 - *Testing position for measuring ankle pronator strength.*

1.3 Description and Scoring of the PDT-Com Movement Competency Tests

A short paragraph on the clinical and practical implications related to the findings of the movement tests will follow each description. The subject is asked to repeat each exercise three times and a score is recorded based on the number of observed movement dysfunctions by the therapist. All movements are scored on a 1-6 ordinal scale. Subjects perform each movement without footwear. The subject is asked to repeat each exercise a specified number of times and a score is recorded based on the type of movement dysfunctions observed by the rater. A dysfunctional movement can be identified either bilaterally or unilaterally and they apply to all three movements in the test battery.

For the ‘Squat’ exercise they are as follows in order of importance:

- ankle pronation (inward movement of medial malleoli)
- knee valgus (foot/knee alignment)
- lateral hip sway or abduction
- lumbar/thoracic flexion (rounding)
- poor sagittal trunk alignment (with lower limb)
- decreased ROM* (posterior knee flexion angle >90 degrees)

For the ‘Lunge’ exercise they are as follows in order of importance:

- ankle pronation (inward movement of medial malleoli)
- lateral hip sway or abduction (hip/knee alignment)
- knee valgus (foot/knee alignment)
- poor sagittal trunk alignment (with lower limb)
- decreased ROM* (posterior knee flexion angle >90 degrees)

- poor frontal trunk alignment (lateral torso flexion)

For the ‘single leg squat’ exercise they are as follows in order of importance:

- ankle pronation (inward movement of medial malleoli)
- knee valgus (foot/knee alignment)
- Loss of balance
- poor sagittal trunk alignment (with lower limb)
- decreased ROM* (posterior knee flexion angle >90 degrees)
- poor frontal trunk alignment (lateral torso flexion)

The following sections describe the three fundamental movements involved in the PDT-Com assessment tool and how each movement is executed.

The Squat

The squat is a fundamental human movement that is required for many activities of daily living (ADLs). The squat is a compound movement which challenges muscle and joint symmetry of both the upper and lower-body. This test will give a clear indication of the subject's ability to flex at the ankle, knee and hip in a co-ordinated and controlled show of strength and stability. Having the arms crossed in front of the body enables the therapist to assess bilateral symmetry, and the ability to control the trunk through observing forward lean and/or lateral flexion.

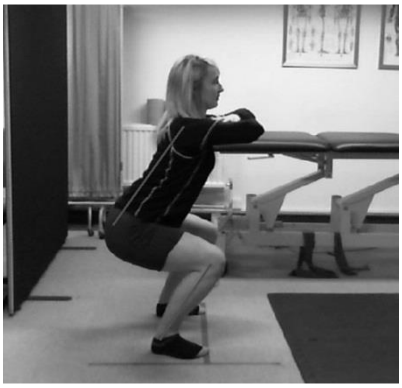
(a)  (b) 

Figure 56 – Ideal s*quat positions lateral view (a) and rear view (b).*

The subject is directed by the therapist to adopt the starting position which is crossing the arms in front of the body parallel with the ground, feet shoulder width apart and slightly gaited (turned outwards). The subject is then instructed to slowly squat by lowering the body towards the floor (Figure 11). The correct position should be stable with the heels in contact with the floor, a neutral ankle position, both knees should be aligned with the feet, head and chest facing forwards with no lateral sway (Figure 11 (a) & (b)), and an upright torso with arms parallel to the floor (Figure 11 (b)).

PDT Scoring Criteria - Squats			
Rear View			
Sagittal View			
Score	**1**	**2**	**3**
Criteria	• Ankle Pronation • Knee valgus • Lateral shift • Knee flexion <90 degrees • Lumbar/thoracic flexion • Poor sagittal trunk alignment	• Ankle pronation • Knee valgus • Lateral shift • Lumar/thoracic flexion	• Ankle pronation • Knee valgus **+** Any other observed dysfunction
Rear View			
Sagittal View			
Score	**4**	**5**	**6**
Criteria	• Ankle pronation **OR** • Knee valgus **+** Any other observed dysfunction	• knee flexion <90 degrees **OR** • Poor sagittal trunk alignment	No observed dysfunctions

Figure 57 – *PDT-Com scoring for the Squat movement*

Clinical implications for the squat include the ability to perform a closed kinetic chain movement of dorsiflexion (ankles), flexion (knees, hips & shoulders), abduction (hips) and extension (lumbar & thoracic spine). An inability to perform this fundamental movement well can be the result of several limiting factors. Poor mobility in the lower-extremity, in particular excessive ankle pronation, poor ankle dorsiflexion range, knee valgus and lumbar/thoracic spine mobility, may be the underlying factor/s for poor test performance.

The Lunge

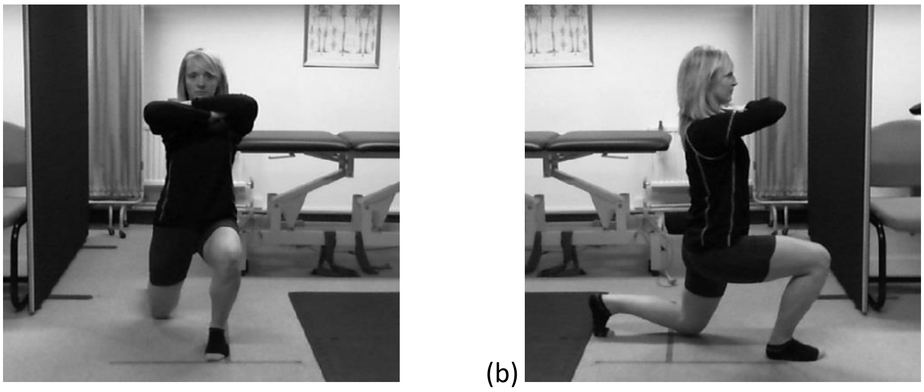
The lunge test places the subject's body in a position that challenges unilateral deceleration, rotation and balance. It is a prime illustration of the fundamentals of walking and running mechanics, in particular the ability to resist rotation to control the body and maintain proper alignment. The lunge test specifically assesses ankle and knee mobility and stability, ankle, knee and hip alignment, flexibility of the lower-extremity muscles and torso control.

(a)  (b) 

Figure 58 - *Lunge starting position showing measurement line (a), and how the measurement is applied (b).*

The subject's feet are placed hip width apart with one foot placed behind. The subject is directed by the therapist to adopt the starting position which is crossing the arms in front of the body parallel with the ground. For correct rear foot placement the therapist measures with a tape measure the distance from the floor to the end of the fingers (Figure 13 a). This measurement is then applied from the heel of the front foot to the toe of the rear foot to establish a minimum distance (Figure 13 b).

The subject is then instructed to slowly lower the body towards the floor flexing the hip and knee as far as possible or until the rear knee brushes the ground (Figure 14). The correct position should be stable with the front heel in contact with the floor, a neutral ankle position; the front knee should be aligned with the foot and hip, both head and chest facing forwards with no lateral flexion or sway, and an upright torso with arms parallel with the floor (Figure 14).



(a) (b)

Figure 59 - *Lunge position frontal view (a) and lateral view (b.*

Clinical implications for the lunge include the subject's ability to stabilise the ankle, knee and hip as well as control hip abduction. The lunge also requires mobility of the front limb control in the form of ankle dorsi flexion, rectus femoris flexibility and strength in the gluteal (buttock) region. In addition, the subject must also display adequate balance to resist lateral stress imposed by the split stance (Figure 14).

Poor performance during the lunge can be the result of inadequate flexibility throughout the kinetic chain, but specifically in the hip flexors and gluteal muscles. Performance can also be compromised by strength imbalances between the abductors and the adductor muscle groups (Figure 15 b).

Clinical implications for the lunge include the subject's ability to stabilise the ankle, knee and hip as well as control hip abduction. The lunge also requires mobility of the front limb control in the form of ankle dorsi flexion, rectus femoris flexibility and strength in the gluteal (buttock) region. In addition, the subject must also display adequate balance to resist lateral stress imposed by the split stance (Figure 14).

PDT Scoring Criteria - Lunge			
Frontal View			
Sagittal View			
Score	**1**	**2**	**3**
Criteria	• Ankle Pronation • Lateral hip shift • Knee valgus • Poor sagittal trunk alignment • Front knee flexion <90 degrees • Poor frontal trunk alignment	• Ankle Pronation • Lateral hip shift • Knee valgus • Poor sagittal trunk alignment	• Ankle pronation • Lateral hip shift **+** Any other observed dysfunction
Frontal View			
Sagittal View			
Score	**4**	**5**	**6**
Criteria	• Ankle pronation **OR** • Lateral hip shift **+** Any other observed dysfunction	• Poor frontal trunk alignment **OR** • Front knee flexion <90 degrees	No observed dysfunctions

Figure 60 – *PDT-Com scoring for the Lunge movement*

Poor performance during the lunge can be the result of inadequate flexibility throughout the kinetic chain, but specifically in the hip flexors and gluteal muscles. Performance can also be compromised by strength imbalances between the abductors and the adductor muscle groups (Figure 15). Similarly, an imbalance between abductor and adductor flexibility can also result in poor performance of this test. Mobility limitations may exist in the lower-limb (causing heel lift) and the torso causing forward lean and/or reduced ROM, which can result in limited movement and instability (Figure 15).

The Single Leg Squat

The single leg squat (SLSQ) is the most advanced movement in the PDT-Com test battery. It is similar in many ways to the lunge but places greater stresses through the knee and hip complex. The unilateral nature of this movement requires the subject to generate greater amounts of lower-extremity muscle force to resist rotation, maintain proper alignment and remain stable in a single leg stance. The SLSQ in particular highlights left/right functional limitations and imbalances which can be a precursor to more serious MSK dysfunctions.

The subjects assume the starting position standing on one leg with the foot facing forwards. The non-weight bearing leg is flexed forwards and the arms are raised in front of the body parallel to the ground (Figure 16). The subject is then asked to lower their body to the ground as far as possible whilst maintaining alignment and balance. The correct position should be stable with the stance leg heel in contact with the floor, a neutral ankle position; the knee should be aligned with the foot and hip, both head and chest facing forwards with no lateral flexion or sway (Figure 16).

(a) 

(b) 

Figure 61 - *SLSQ position frontal view (a) and lateral view (b).*

Similar to the lunge exercise, poor performance during the SLSQ can be the result of inadequate flexibility throughout the kinetic chain. Mobility limitations may exist in the lower-limb (causing heel lift) and the torso causing reduced ROM, which can result in limited movement and instability (Figure 17). The determining factor for success in this exercise is sufficient strength in the hip complex and knee extensor/flexors.

Weakness in these muscles renders the subject unable to resist rotation forces causing unwanted ankle pronation, knee valgus and hip rotation (Figure 17). The ability to only score highly on one side indicates impairments in lower-extremity muscle groups and warrants further investigation.

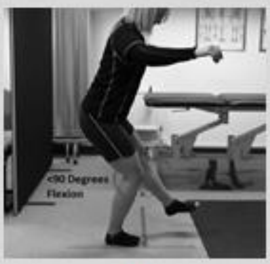
PDT Scoring Criteria - SLSQ			
Frontal View			
Sagittal View			
Score	**1**	**2**	**3**
Criteria	• Ankle Pronation • Knee valgus • Loss of balance • Poor sagittal trunk alignment • Knee flexion <90 degrees • Poor frontal plane trunk alignment	• Ankle pronation • Knee valgus • Loss of balance • Poor sagittal trunk alignment	• Ankle pronation • Knee valgus **+** Any other observed dysfunction
Frontal View			
Sagittal View			
Score	**4**	**5**	**6**
Criteria	• Ankle pronation **OR** • Knee valgus **+** Any other observed dysfunction	• Poor frontal plane trunk alignment **OR** • knee flexion <90 degrees	No observed dysfunctions

Figure 62 – *PDT-Com scoring for the SLSQ movement*

1.4 Summary

In higher-functioning older people the modifiable physical factors that are associated with a change in status from non-faller to faller need identifying. Well established correlates with fall risk and physical function are lower-extremity muscle weakness and impairments in mobility, gait and balance.

The PDT-Com is an integrated, functional approach to physical performance testing which incorporates the principles of direct muscle force measurements (hand-held dynamometry) and movement competency. This assessment, then, enables the direct evaluation of lower-extremity muscle strength and fundamental movement patterns of individuals in a dynamic and functional capacity.

1.5 Appendices

1.5.1 Appendix 1 - PDT-Com HHD Scoring Values (Non-Dominant Side)

Table 44 PDT-Com Scoring System (Non-Dominant Side) Presented by Muscle Action, Gender & Side

		PDT-Com Scoring System (Non-Dominant Side)											
Muscle Action	Gender	1		2		3		4		5		6	
Non-Dominant Dorsiflexion	F	0.0	95.0	95.1	117.9	118.0	140.7	140.8	163.6	163.7	186.5	186.6	∞
	M	0.0	117.5	117.6	155.6	155.7	193.6	193.7	231.7	231.8	269.8	269.9	∞
Non-Dominant Eversion	F	0.0	60.7	60.8	80.0	80.1	99.4	99.5	118.7	118.8	138.0	138.1	∞
	M	0.0	102.8	102.9	122.1	122.2	141.3	141.4	160.6	160.7	179.9	180.0	∞
Non-Dominant Inversion	F	0.0	62.4	62.5	81.7	81.8	101.0	101.1	120.2	120.3	139.5	139.6	∞
	M	0.0	94.3	94.4	114.3	114.4	134.4	134.5	154.5	154.6	174.5	174.6	∞
Non-Dominant Plantar flexion	F	0.0	180.9	181.0	219.4	219.5	257.8	257.9	296.3	296.4	334.8	334.9	∞
	M	0.0	234.0	234.1	281.1	281.2	328.1	328.2	375.2	375.3	422.2	422.3	∞
Non-Dominant Hip Extension	F	0.0	107.5	107.6	132.9	133.0	158.4	158.5	183.8	183.9	209.3	209.4	∞
	M	0.0	171.0	171.1	201.4	201.5	231.8	231.9	262.2	262.3	292.6	292.7	∞
Non-Dominant Hip Abduction	F	0.0	67.6	67.7	81.0	81.1	94.3	94.4	107.6	107.7	120.9	121.0	∞
	M	0.0	111.4	111.5	125.6	125.7	139.9	140.0	154.1	154.2	168.3	168.4	∞
Non-Dominant Hip Adduction	F	0.0	60.0	60.1	72.7	72.8	85.5	85.6	98.2	98.3	110.9	111.0	∞
	M	0.0	91.9	92.0	111.4	111.5	130.9	131.0	150.4	150.5	169.9	170.0	∞
Non-Dominant Knee Flexion	F	0.0	36.8	36.9	54.7	54.8	72.7	72.8	90.7	90.8	108.7	108.8	∞
	M	0.0	56.6	56.7	76.0	76.1	95.4	95.5	114.8	114.9	134.2	134.3	∞
Non-Dominant Hip Flexion	F	0.0	100.4	100.5	116.0	116.1	131.6	131.7	147.2	147.3	162.8	162.9	∞
	M	0.0	166.4	166.5	181.9	182.0	197.4	197.5	212.9	213.0	228.4	228.5	∞
Non-Dominant Knee Extension	F	0.0	140.6	140.7	167.6	167.7	194.6	194.7	221.6	221.7	248.5	248.6	∞
	M	0.0	205.0	205.1	241.1	241.2	277.3	277.4	313.4	313.5	349.5	349.6	∞

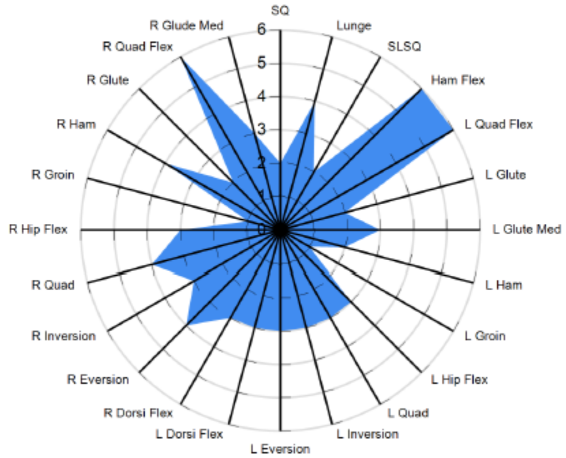
1.5.2 Appendix 2 - PDT-Com HHD Scoring Values (Dominant Side)

Table 45 PDT-Com Scoring System (Dominant Side) Presented by Muscle Action, Gender & Side

		PDT-Com Scoring System (Dominant Side)											
Muscle Action	Gender	1		2		3		4		5		6	
Dominant Dorsiflexion	F	0.0	97.2	97.3	121.5	121.6	145.8	145.9	170.1	170.2	194.4	194.5	∞
	M	0.0	121.4	121.5	155.7	155.8	190.1	190.2	224.5	224.6	258.8	258.9	∞
Dominant Eversion	F	0.0	58.3	58.4	78.2	78.3	98.1	98.2	118.0	118.1	137.8	137.9	∞
	M	0.0	102.5	102.6	123.2	123.3	143.8	143.9	164.5	164.6	185.1	185.2	∞
Dominant Inversion	F	0.0	56.9	57.0	78.6	78.7	100.2	100.3	121.8	121.9	143.5	143.6	∞
	M	0.0	86.1	86.2	111.4	111.5	136.6	136.7	161.8	161.9	187.0	187.1	∞
Dominant Plantar flexion	F	0.0	190.7	190.8	229.3	229.4	268.0	268.1	306.6	306.7	345.3	345.4	∞
	M	0.0	258.0	258.1	305.5	305.6	352.9	353.0	400.3	400.4	447.7	447.8	∞
Dominant Hip Extension	F	0.0	96.8	96.9	124.4	124.5	152.0	152.1	179.6	179.7	207.2	207.3	∞
	M	0.0	158.6	158.7	195.0	195.1	231.4	231.5	267.8	267.9	304.2	304.3	∞
Dominant Hip Abduction	F	0.0	67.0	67.1	81.1	81.2	95.1	95.2	109.1	109.2	123.2	123.3	∞
	M	0.0	107.5	107.6	125.5	125.6	143.5	143.6	161.4	161.5	179.4	179.5	∞
Dominant Hip Adduction	F	0.0	67.0	67.1	78.1	78.2	89.1	89.2	100.1	100.2	111.1	111.2	∞
	M	0.0	96.0	96.1	113.9	114.0	131.9	132.0	149.9	150.0	167.9	168.0	∞
Dominant Knee Flexion	F	0.0	45.2	45.3	61.1	61.2	77.1	77.2	93.1	93.2	109.0	109.1	∞
	M	0.0	57.2	57.3	80.2	80.3	103.3	103.4	126.3	126.4	149.3	149.4	∞
Dominant Hip Flexion	F	0.0	102.3	102.4	119.1	119.2	135.9	136.0	152.7	152.8	169.5	169.6	∞
	M	0.0	173.7	173.8	189.0	189.1	204.4	204.5	219.8	219.9	235.2	235.3	∞
Dominant Knee Extension	F	0.0	143.9	144.0	171.8	171.9	199.7	199.8	227.6	227.7	255.4	255.5	∞
	M	0.0	213.0	213.1	247.9	248.0	282.8	282.9	317.7	317.8	352.6	352.7	∞

1.5.3

Appendix 3 - PDT-Com Composite Output Graph



PDT Composite Scores

Hip	Raw	%
Left	14	38.9
Right	17	47.2
Flexion	13	54.2
Extension	10	41.7
Total	31	43.1
Lower-limb		
Left	9	37.5
Right	10	41.7
Total	19	39.6

	Raw	%
Total Left	23	38.3
Total Right	27	45.0
Movement	8	44.4
Flexibility	18	100.0
Total composite	76	48.7

12.17 APPENDIX Q - SEARCH STRATEGY (CHAPTER 6)

Searches were adapted to all databases.

1. Muscle Strength/
2. Lower Extremity/
3. (leg strength* or lower leg strength* or lower limb strength* or lower extremity strength* or maxim* strength* or ankle strength* or knee strength* or hip strength*).ti,ab,kw.
4. or/1-3
5. AGED/
6. "AGED, 80 AND OVER"/
7. AGING/
8. GERIATRICS/
9. Geriatric Assessment/
10. ((older adj2 adult$) or elder$ or old$ or age$ or aging or geriatric$ or senior$ or gerontolog$ or pensioner$).ti,ab,kw.
11. ("65 year$" or "over 65" or "70 year$" or "over 70" or "75 year$" or "over 75" or "80 year$" or "over 80" or "85 year$" or "over 85").ti,ab,kw.
12. or/5-11
13. (objective* or tool* or instrument* or evaluat*).ti,ab,kw.
14. (instrumentation or methods).sh.
15. (Validation Studies or Comparative Study).pt.
16. exp Psychometrics/
17. psychometr*.ti,ab.
18. (clinimetr* or clinometr*).tw.
19. exp Outcome Assessment Health Care/
20. outcome assessment.ti,ab.
21. outcome measure*.tw.
22. exp Observer Variation/
23. observer variation.ti,ab.
24. exp Health Status Indicators/
25. exp Reproducibility of Results/
26. reproducib*.ti,ab.
27. exp Discriminant Analysis/
28. (reliab* or unreliab* or valid* or coefficient or homogeneity or homogeneous or internal consistency).ti,ab.
29. (cronbach* and (alpha or alphas)).ti,ab.
30. (item and (correlation* or selection* or reduction*)).ti,ab.
31. (agreement or precision or imprecision or precise values or test-retest).ti,ab.
32. (test and retest).ti,ab.
33. (reliab* and (test or retest)).ti,ab.
34. (stability or interrater or inter-rater or intrarater or intra-rater or intertester or inter-tester or intratester or intra-tester or interobserver or inter-observer or intraobserver or intraobserver or intertechnician or inter-technician or intratechnician or intra-technician or interexaminer or inter-examiner or intraexaminer or intra-examiner or interassay or interassay or intraassay or intra-assay or interindividual or inter-individual or intraindividual or intra-individual or interparticipant or inter-

participant or intraparticipant or intra-participant or kappa or kappas or repeatab*).ti,ab.

35. ((replicab* or repeated) and (measure or measures or findings or result or results or test or tests)).ti,ab.

36. (generaliza* or generalisa* or concordance).ti,ab.

37. (intraclass and correlation*).ti,ab.

38. (discriminative or known group or factor analysis or factor analyses or dimension* or subscale*).ti,ab.

39. (item discriminant or interscale correlation* or error or errors or individual variability).ti,ab.

40. (variability and (analysis or values)).ti,ab.

41. (uncertainty and (measurement or measuring)).ti,ab.

42. ("standard error measurement" or sensitiv* or responsive*).ti,ab.

43. ((minimal or minimally or clinical or clinically) and (important or significant or detectable) and (change or difference)).ti,ab.

44. (small* and (real or detectable) and (change or difference)).ti,ab.

45. (meaningful change or ceiling effect or floor effect).ti,ab.

46. or/13-45

47. 4 and 12

48. 46 and 47

49. 48 not (addresses or biography or case reports or comment or directory or editorial or festschrift or interview or lectures or legal cases or legislation or letter or news or newspaper article or patient education handout or popular works or congresses or consensus development conference or consensus development conference or practice guideline).mp. not (animals not humans).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]

50. limit 49 to full text

51. limit 49 to ovid full text available

12.18 APPENDIX R – EXAMPLE INCLUSION/EXCLUSION CRITERIA CHECKLIST

Reference	Reviewers	Age >65yrs?	Healthy Community-dwelling?	Lower-extremity strength?	Measurement Properties?	Meets Criteria?	Reasons why paper excluded
		Y/N/U	Y/N/U	Y/N/U	Y/N/U	Y/N/U	Comments
#1 - Arnold	SB						
	JB						
	SG						

12.19 APPENDIX S – DATA EXTRACTION FORM

Ax Tool & Reference	Reliability			Measurement Error			Construct Validity			Criterion Validity		
	n	Meth Qual	Result (rating)	n	Meth Qual	Result (rating)	n	Meth Qual	Result (rating)	n	Meth Qual	Result (rating)
Tool A												
Study #1												
Study #2												
Study #3												
Tool B												

12.20 APPENDIX T – SUMMARY TABLE OF RESULTS FOR MEASUREMENT PROPERTIES

Ax Tool & Reference	Reliability			Measurement Error			Construct Validity			Criterion Validity		
	n	Meth Qual	Result (rating)	n	Meth Qual	Result (rating)	n	Meth Qual	Result (rating)	n	Meth Qual	Result (rating)
Hand-Held Dynamometry (HHD)												
Arnold (2010) (218)	18	Very Good	ICC (agreement) > 0.70 (+); not for dorsiflexion (< 0.70) (-)	18	Very Good	SEM (kg) = 0.96 - 1.89	18	Very Good	+	18	Very Good	Isokinetic Dynamometer - ICC 0.44 – 0.85 (+/-); r = 0.57 – 0.86 (+)
Awwad (2017) (370)	21	Adequate	Inter-rater ICC 0.92 – 0.94 (+); Intra-rater ICC 0.94 (+)	21	Adequate	LoA (inter-rater) 2.4%	21	Very Good	+	21	Very Good	Isokinetic Dynamometer - ICC 0.79 – 0.84 (+); LoA (criterion) 5.0 - 5.2%
Bieler (2014) (371)	37	Adequate	ICC (agreement) 0.89 (+)	37	Adequate	MDC = 98.2						
Bohannon (2001) (223)	55	Adequate	Inter-rater ICC 0.88 (+)				55	Very Good	PFS (SF-36) actual r = 0.38 (-); normalised r = 0.52 (+)			

Bohannon (2014)							40	Adequate	Internal Consistency α = 0.78 – 0.75 (+); Other HHD Protocol r = 0.35 – 0.58 (+/-); STS AUC = 0.63 (+)			
Richardson (1998)	20	Adequate	Inter-rater ICC 0.74 (+); Intra-rater ICC = 0.95 (+)	20	Adequate	Inter-rater SEM 1.74 – 1.84; Intra-rater SEM 3.16 – 3.41						
Pooled Results (overall rating)	**131**	**Adequate**	**ICC (inter-rater) 0.70 – 0.95 (+); (intra-rater) > 0.70 (+)**		**Adequate**	**(+)**	**134**	**Very Good**	**α = 0.78 – 0.75 (+); r = 0.35 – 0.58 (+/-); AUC 0.63 (+)**	**39**	**Very Good**	**r = 0.57 – 0.86 (+); ICC 0.44 – 0.85 (+/-)**

Key: SEM = Standard Error of Measurement; ICC = Intraclass Correlation Coefficient; HHD = Hand-Held Dynamometer; r = Pearson's Correlation Coefficient; α = Cronbach Alpha; LoA = Limits of Agreement; SRD = Smallest Real Difference; AUC = Area Under the Curve; (+) = high reliability (ICC ≥ 0.70), high construct validity (correlation between constructs ≥ 0.50), high concurrent/criterion validity (Pearson Correlation or AUC ≥ 0.70); (-) = low reliability (ICC < 0.70), low validity (correlation between constructs < 0.50), low concurrent/criterion validity (Pearson Correlation or AUC < 0.70); LEP = Lower Extremity Power.

Ax Tool & Reference	Reliability			Measurement Error			Construct Validity			Criterion Validity		
	n	Meth Qual	Result (rating)	n	Meth Qual	Result (rating)	n	Meth Qual	Result (rating)	n	Meth Qual	Result (rating)
HHD Belt-Resisted												
Desrosiers (1998	28 (inter-rater; 27 Intra-rater	Adequate	Intra-rater ICC 0.79 – 0.95 (+); Inter-rater ICC 0.64 – 0.92 (+/-)									
Katoh (2010)	186	Adequate	ICC > 0.90 (+)	186	Adequate	LoA -5.6 – 4.6						
Pooled Results (overall rating)	**214**	**Adequate**	**+/-**									
Isokinetic Dynamometer												
Holmback (2007)	30	Very Good	ICC (intra-rater) 0.94 – 0.98 (+)	30	Very Good	SEM < 2.3Nm; SRD = -7.2Nm – 5.6Nm						
Kramer (2001)	28	Very Good	ICC (males) = 0.90 (+), (females = 0.74 (+);	28	Very Good	SEM (males) ± 16, (females) ± 14						
Ordway (2006)	33	Inadequate	LoA < 8 Nm	33	Very Good	LoA Ratio 21 – 43%						

Van Driessche (2018)	63	Very Good	ICC 0.85 – 0.98 (+)	63	Very Good	SEM 3 – 10%						
Holsgaard Larsen (2006)	18	Inadequate	Test/retest (plantar flexors) r = 0.65 – 0.87 (+/-); (hamstring) r = 0.64 – 0.91 (+/-); (quadriceps) r = 0.81 – 0.87 (+)	18	Inadequate	CV (plantar flexors) = 10 – 18%; (hamstring) = 7 – 19%; (quadriceps) = < 10%						
Pooled Results (overall rating)	**109**	**Adequate**	**ICC (intra-rater) 0.74 – 0.98 (+/-); r = 0.64 – 0.91 (+/-)**	**109**	**Very Good**	**SEM ± 16; SEM% 3 – 10%; SRD = -7.2Nm – 5.6Nm; CV <18%**						

Key: SEM = Standard Error of Measurement; ICC = Intraclass Correlation Coefficient; HHD = Hand-Held Dynamometer; r = Pearson's Correlation Coefficient; α = Cronbach Alpha; LoA = Limits of Agreement; SRD = Smallest Real Difference; AUC = Area Under the Curve; (+) = high reliability (ICC ≥ 0.70), high construct validity (correlation between constructs ≥ 0.50), high concurrent/criterion validity (Pearson Correlation or AUC ≥ 0.70); (-) = low reliability (ICC < 0.70), low validity (correlation between constructs < 0.50), low concurrent/criterion validity (Pearson Correlation or AUC < 0.70); LEP = Lower Extremity Power.

Ax Tool & Reference	Reliability			Measurement Error			Construct Validity			Criterion Validity		
	n	**Meth Qual**	**Result (rating)**	**n**	**Meth Qual**	**Result (rating)**	**n**	**Meth Qual**	**Result (rating)**	**n**	**Meth Qual**	**Result (rating)**
Nintendo Wii Board												
Gronbech Jorgensen (2015)	30	Adequate	ICC (agreement) 0.90 – 0.98 (+)	30	Very Good	SEM 9.7 – 13.9%; LoA 20.3 – 28.7%				30	Very Good	SID - ICC = > 0.8 (+)
Keiser A420 Leg Press												
LeBrasseur (2008)	31	Adequate	ICC (test-retest agreement) = 0.94 (+)	31	Adequate	LoA (Bias) = 1.1% (21.1N)						
Squat												
Sato (2018)							28	Very Good	HHD r = 0.88 (+)	20	Very Good	Isokinetic Dynamometer r = 0.84 (+)

Key: SEM = Standard Error of Measurement; ICC = Intraclass Correlation Coefficient; HHD = Hand-Held Dynamometer; SID = Stationary Isometric Dynamometer; r = Pearson's Correlation Coefficient; α = Cronbach Alpha; LoA = Limits of Agreement; SRD = Smallest Real Difference; AUC = Area Under the Curve; (+) = high reliability (ICC ≥ 0.70), high construct validity (correlation between constructs ≥ 0.50), high concurrent/criterion validity (Pearson Correlation or AUC ≥ 0.70); (-) = low reliability (ICC < 0.70), low validity (correlation between constructs < 0.50), low concurrent/criterion validity (Pearson Correlation or AUC < 0.70); LEP = Lower Extremity Power.

Myometer												
Smith (1996)	6	Adequate	ICC (hip abductor) 0.98 (+); (hip extensor) 0.99 (+)	6	Adequate	CV (hip abductor) = 4.7%; (hip extensor) = 7.2	20	Very Good	LEP r = 0.61 (+); Walking Speed r = 0.54 (+); Functional Reach r = 0.57 (+)			
Leg Press Sled												
Hutchison (2006)	11	Very Good	ICC >0.90 (+)	11	Very Good	SEM 19.8 – 23.1				11	Very Good	Isokinetic Dynamometer r = 0.74 – 0.81 (+)

Key: SEM = Standard Error of Measurement; ICC = Intraclass Correlation Coefficient; HHD = Hand-Held Dynamometer; SID = Stationary Isometric Dynamometer; r = Pearson's Correlation Coefficient; α = Cronbach Alpha; LoA = Limits of Agreement; SRD = Smallest Real Difference; AUC = Area Under the Curve; (+) = high reliability (ICC ≥ 0.70), high construct validity (correlation between constructs ≥ 0.50), high concurrent/criterion validity (Pearson Correlation or AUC ≥ 0.70); (-) = low reliability (ICC < 0.70), low validity (correlation between constructs < 0.50), low concurrent/criterion validity (Pearson Correlation or AUC < 0.70); LEP = Lower Extremity Power.